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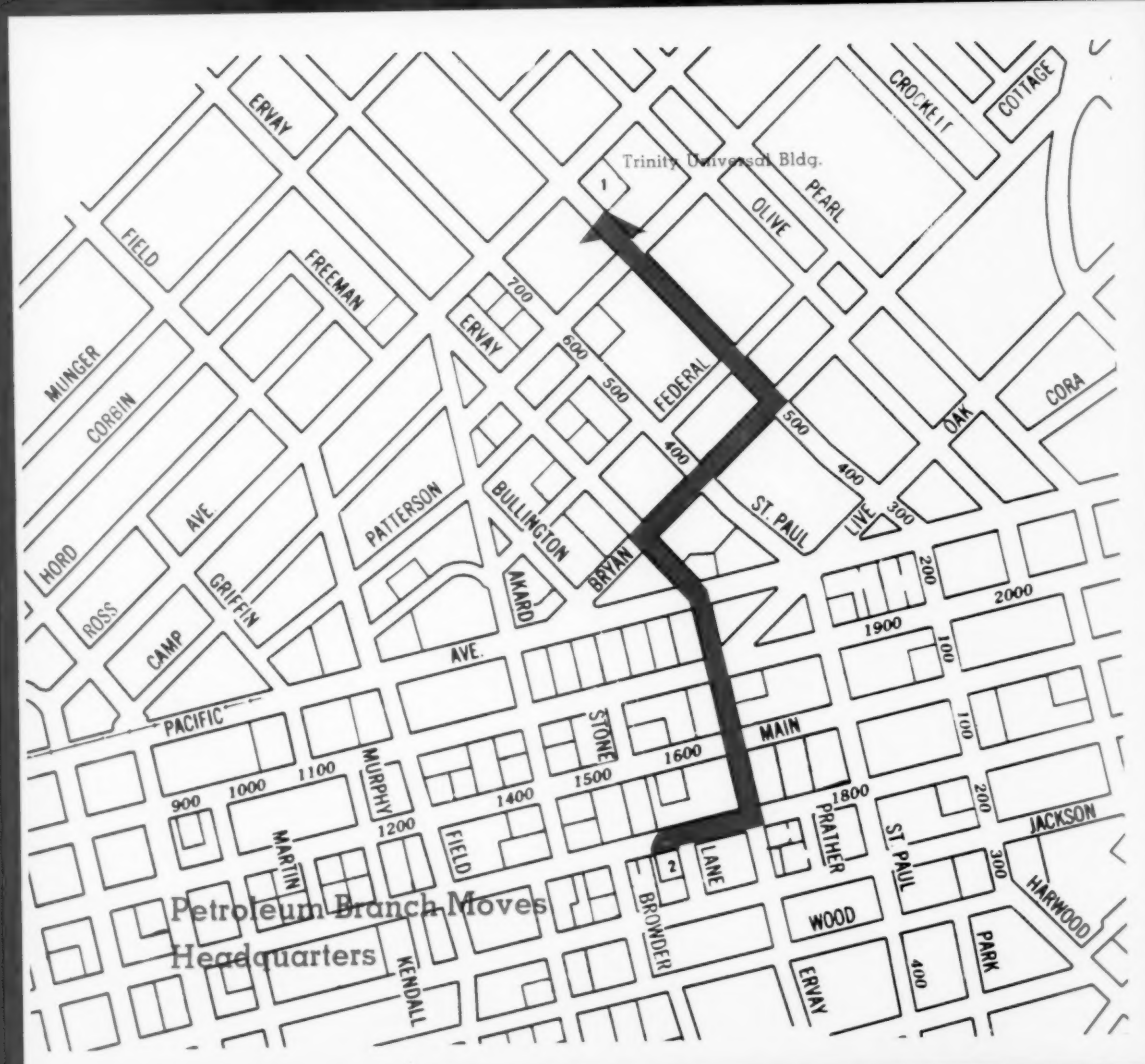

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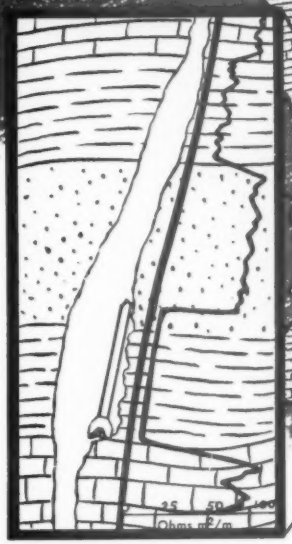

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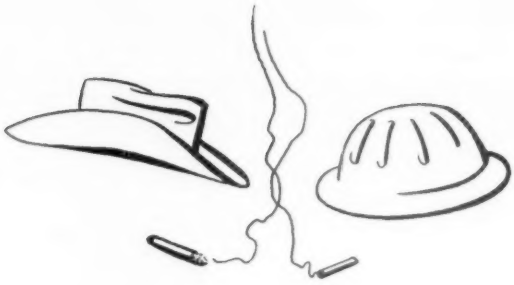

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Journal of Petroleum Technology

Vol. III MAY, 1951 No. 5

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On the Cover — A map of Downtown Dallas, Tex., means little, if anything, to anyone except a Dallasite. However, this month one does serve to portray graphically the slight shift in Petroleum Branch headquarters. The building marked "1" is the new site of Branch headquarters — 408 Trinity Universal Bldg. At the other end of the line (building marked "2") is the Continental Bldg., whence headquarters were moved. For more details of the move, see the story on Page 3, Section 2. Cover map reprinted courtesy J. Foster Ashburn Map Co.

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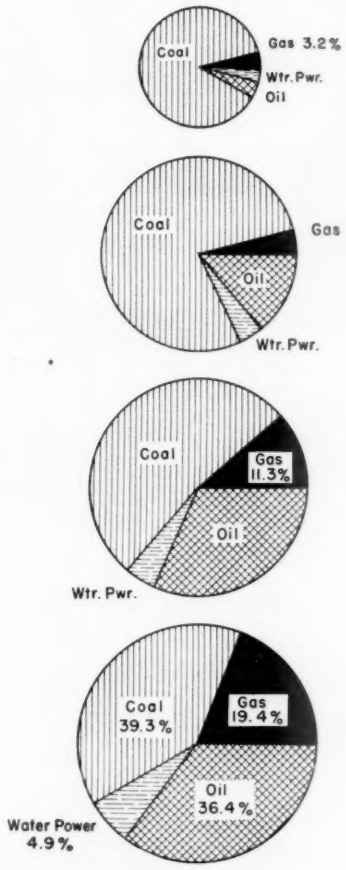

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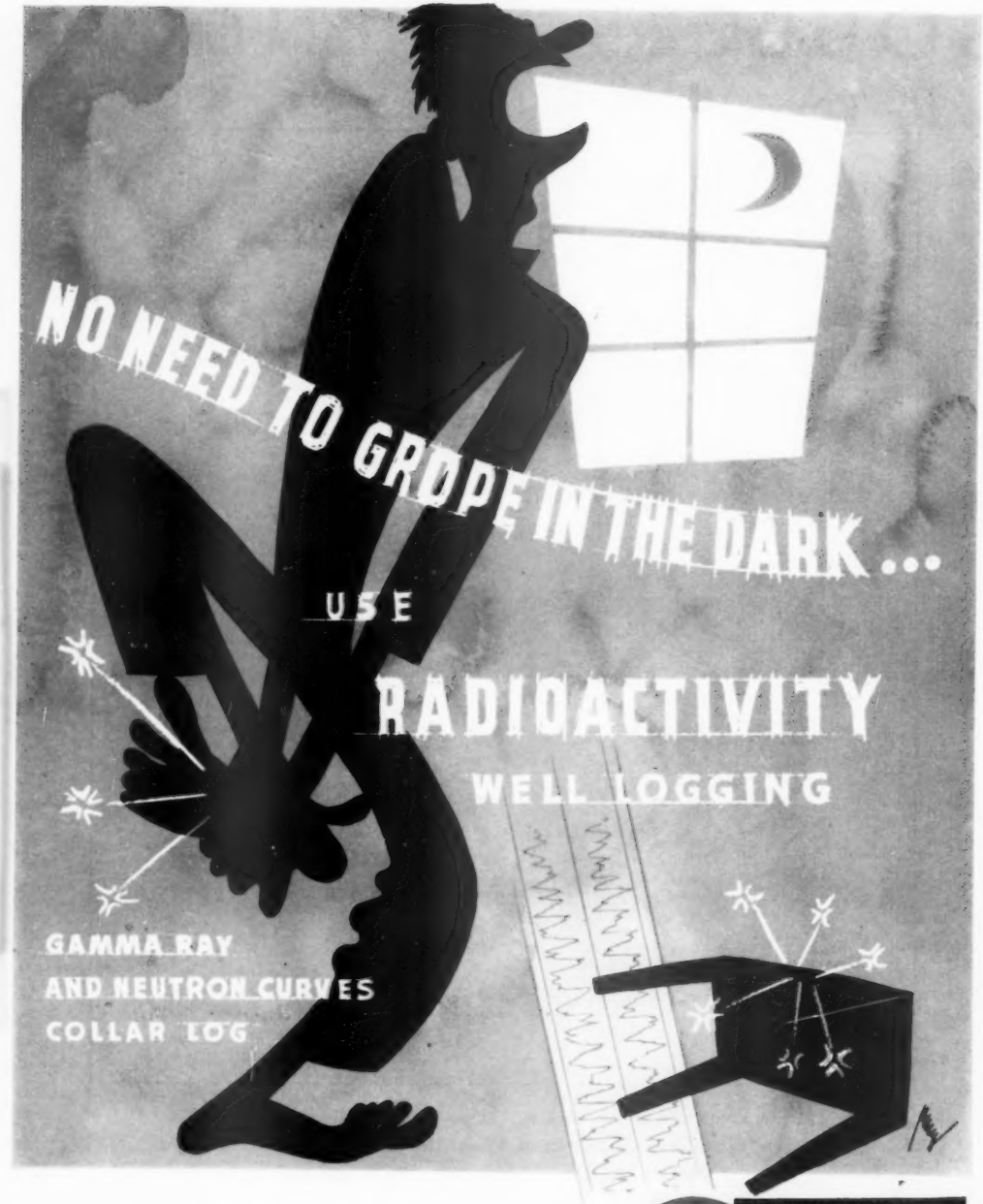

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Meets Varied Production Requirements

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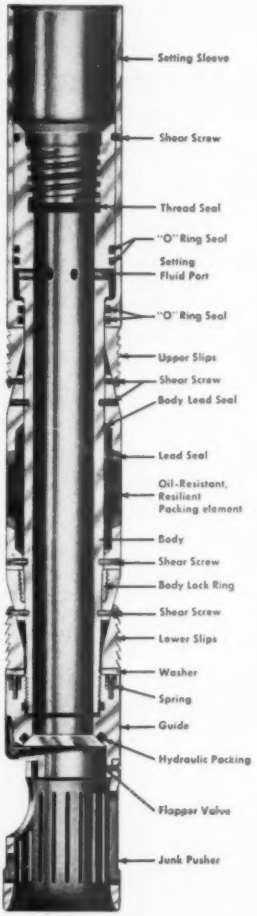

Baker Model "D" Retainer Production Packer shown ready to run in the well, but prior to introduction of Setting Tool shown in Figure 1.

The Baker Retainer Production Packer is used for single-zone production to prevent gas from cutting holes in the casing (often started by thread leaks) by transferring the pressure from the casing to the tubing. If and when the tubing leaks, it can be pulled, repaired and replaced through the Packer. The Packer will protect the casing when corrosive fluid is being produced or injected, by permitting the annulus to be filled with oil and confining the corrosive action to the tubing only.

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Many Important Advantages

Let us consider the major advantages which make the Baker Model "B" Retainer Production Packer so economical, so easy and safe to run and operate . . . IT HOLDS BOTH WAYS – The Packer is anchored against either upward or downward movement by two full sets of opposing slips. This feature is always desirable, and is vital in gas-injection or water-injection wells where

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Baker "Universal Type" Packer

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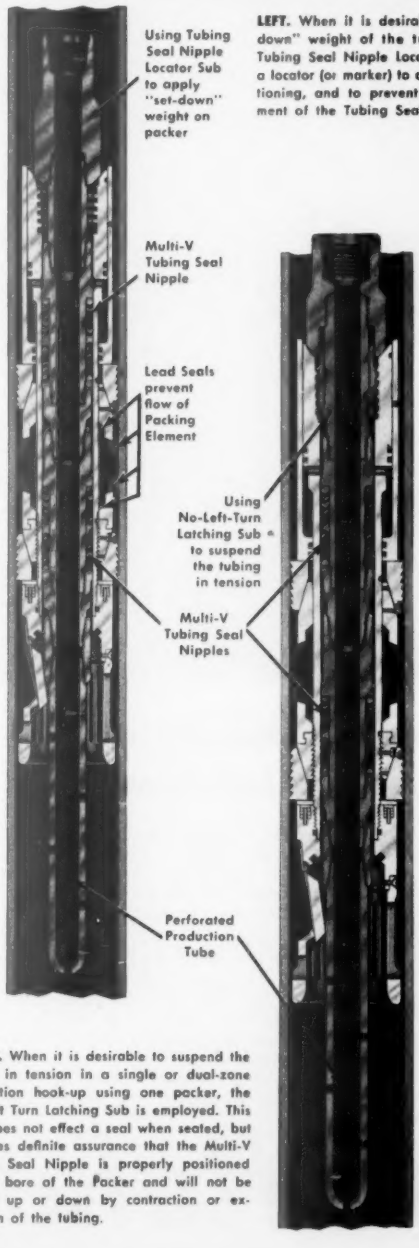
In addition to conventional setting on tubing or drill pipe, WIRE LINE SETTING of the Baker Retainer Production Packer is available through several leading service organizations. Any Baker office or representative will furnish complete information.


Using Tubing Seal Nipple Locator Sub to apply "set-down" weight on packer
Multi-V Tubing Seal Nipple
Lead Seals prevent flow of Packing Element
Using No-Left-Turn Latching Sub to suspend the tubing in tension
Multi-V Tubing Seal Nipples
Perforated Production Tube

LEFT. When it is desirable to apply "set-down" weight of the tubing string, the Tubing Seal Nipple Locator Sub serves as a locator (or marker) to assure proper positioning, and to prevent downward movement of the Tubing Seal Nipple.

RIGHT. When it is desirable to suspend the tubing in tension in a single or dual-zone completion hook-up using one packer, the No Left Turn Latching Sub is employed. This unit does not effect a seal when seated, but provides definite assurance that the Multi-V Tubing Seal Nipple is properly positioned in the bore of the Packer and will not be moved up or down by contraction or expansion of the tubing.

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Editorial Comment—

The Petroleum Engineer's Place In the Defense Economy

By R. G. Lawton
Director of Production, Petroleum Administration for Defense

PERHAPS no industry has ever shown more intense interest and determination in reducing costs, improving operating methods, and conserving natural resources and materials through study, research, invention and engineering ingenuity than the petroleum industry. Evidence of progress is reflected in all phases of the business, but nowhere have these technological advances been more evident than in the drilling and producing branches of the industry.

Much of this progress in conservation methods and in better and more economical ways of doing things can be credited to the petroleum engineers. They have been in the forefront in petroleum's march of progress for a number of years.

Petroleum engineers are an indispensable part of today's oil production activity. From the traveling block to the drilling bit, from the drawworks to the storage tank they are constantly applying their skill and ingenuity in shaping better ways to do the job. And, while they're at it, they are figuring out ways and means of getting the maximum amount of oil from every reservoir with the minimum amount of waste.

The petroleum engineer is an inquisitive soul, who constantly asks WHY, not HOW. He will determine the HOW through his skill and ingenuity. What he is chiefly concerned with is the question of WHY a thing won't work; WHY is it done this way or that way; WHY couldn't an improvement be made here, or there; WHY is the life, or the use, of certain tools and equipment limited to certain time or applications? This insatiable curiosity has driven him to uncover many prolific fields for improvement, and his fine technical skill have accounted for numerous innovations and inventions that never would have come into being had it not been for him and his inquisitive mind.

The petroleum engineer has been a boon to the small operator as well as to the large company. His contribution has been felt wherever wells are drilled and oil is produced. He has made possible the recovery of millions of barrels of oil for producers through secondary recovery and repressuring. Artificial lifting methods would not have been produced if he had not asked WHY and HOW. By proper pressure maintenance, it has been possible to increase both the rate of production of individual wells and the ultimate recovery from the reserves from which the wells are producing.

Oil equipment manufacturers likewise have leaned heavily upon his know-how and professional technique in developing tools and machinery for this important phase of the industry's operations.

TODAY, the responsibility of the petroleum engineer is as great or greater perhaps than it has ever been in the history of the oil industry. Because of increased civilian demand, and the defense program, drilling is going forward at an unprecedented rate. It will continue at as high a rate as possible, consistent with the amount of steel and other essential material that can be made available under the stepped-up defense program. The industry's excess producing capacity is far below what it should be. At the beginning of World War II, excess producing capacity, over and above the normal daily production demand, was about 1,300,000 B/D. By the end of the war, this excess producing capacity had been dissipated. Today, we have far less of a cushion of excess producing capacity than we had at the beginning of World War II. Demands are two-thirds higher now than they were then, and steel and other materials needed for drilling and expansion are in short supply.

Ways and means must be found, therefore, for getting the most oil for the smallest possible amount of steel and other necessary materials. Here, the petroleum engineer has an important part to play. His knowledge and ability must be put to use both in getting the greatest possible benefits from the industry's extensive drilling program, and in building up the reserve or excess producing capacity to a point where it would not be dissipated immediately should a more serious emergency arise. His ingenuity and skill have pointed the way in the past. There is every reason to count strongly on his contribution in the days to come. ★ ★ ★

DRILLING AND PRODUCTION PROBLEMS RELATING TO THE WORLAND, WYOMING, FIELD

By L. L. McDonald and J. I. Morris
The Pure Oil Co.

Extremely Toxic High Pressure Gas, Severe Winter Weather at 4,000 Ft Elevation, 10,000-Ft Formation Depths; These Conditions Combine to Make Operations at the Worland Field Among the Nation's Most Difficult

ABSTRACT

Reservoir fluid in the Embar formation at the Worland, Wyoming, field contains hydrogen sulphide in excess of 30 per cent by volume.

Satisfactory working solutions have been found for the majority of the operational problems that developed as a result of the unusual characteristics of the well fluids. The precautions necessary to safely handle this extremely toxic high pressure gas, subsurface hydrate formation, severe winter weather at the 4,000 ft elevation, and the 10,000 ft depth of the producing formation have combined to make operations at this field one of the most difficult in the nation.

INTRODUCTION

Drilling and producing operations in the Worland Field differ from normal primarily because of the high percentage of hydrogen sulphide in well fluids and the formation of hydrocarbon and hydrogen sulphide hydrates. The safeguarding of life from this extremely toxic hydrogen sulphide gas has been given first consideration in the selection of materials, equipment, and techniques used in drilling and producing the field. Practices developed have served as guides in other high percentage hydrogen sulphide fields subsequently developed.

The field is in the north central part of Wyoming, nine miles north of Worland, Washakie County, in the southern part of the Big Horn structural basin. Surface elevations are approximately 4,000 ft. The Big Horn river bisects the field on a north-south line and improved roads serve both parts of the field. Most of the area is irrigated for cultivation, but the northwest part of the field is in semi-arid "badlands" above service from the irrigation canal. Atmospheric temperatures range from minus 40°F to 105°F.

DISCOVERY

The Pure Oil Co. assembled a unitized block of acreage in the Worland area on the basis of a structure indicated by reflection seismograph work. The initial well, Worland Unit 1-E, was spudded near the crest of the structure on June 11, 1945. On Feb. 9, 1946, 10,242 ft of 7-in. casing was set near the top of the Tensleep sand. The well reached a total depth of 11,379 ft in the Big Horn dolomite on March 12, 1946. Unit 1-E was plugged back to 10,131 ft and was perforated from 9,990 ft to 10,055 ft to drill stem test the Embar (Permian). It was necessary to discontinue the test after 13½ minutes as toxic hydrogen sulphide gas endangered the lives of the personnel present. The well was completed with a potential of 165 bbl of 43.5° API gravity light green oil per day with a gas/oil ratio varying from 4,900 to 15,000.

Abnormal decline in well productivity indicated mechanical trouble in the well. Upon running a measuring line in the tubing, it was found to be plugged with hydrates. Considerable time was required to drill out the ice with small wire line tools as new hydrates would form nearly as rapidly as the original were removed. The tubing was finally opened through the approximately 2,800 ft of hydrates.

While making production tests on the well, other problems were encountered. The use of a hot circulating fluid eliminated hydrate trouble but the tubing still had a tendency to plug with a black substance of an asphaltic base combined with foreign materials that were probably derived from drilling mud. After producing into a burn pit for some time, the well finally cleaned itself. Another factor adding to the hazards around the well was that pressure gauges frequently ruptured, permitting escape of toxic gas. Gauges with bourdon tubes of stainless steel or other corrosion resistant metal were tried without satisfactory service. This trouble was finally corrected by using a gauge which isolated well fluid from the bourdon tube assembly. Well pressure was transmitted to the bourdon tube through a glycol filled diaphragm type gauge protector.

The hazards of producing a field containing high percentage of hydrogen sulphide were demonstrated when tubing failure permitted well pressure to enter the circulating system. This pressure opened a crack in a hydraulic swedge nipple between the tree and valve on the circulating system which permitted a large volume of toxic gas to escape. As there was no immediate way to stop the leak, inhabitants in the near vicinity were evacuated. To prevent a dangerous accumulation of toxic gas, the well was set on fire by firing tracer bullets from a high powered rifle into the gas pocket at the well. The well was killed 17 days later by filling tubing and annulus with mud and water pumped through a steel billet that had been welded over a boss on the casing spool.

DEVELOPMENT

Drilling problems in the Worland Field have been concerned mainly with the drilling fluid in order to get maximum drilling efficiency and prevent lost circulation.

Four general types of drilling muds were used with varied results, these being starch, lime, cellulose gum, and caustic quebracho. The most used mud was caustic quebracho, as experience indicated this to be generally satisfactory and more economical.

Although loss of circulation constitutes a major problem in Worland, the most detrimental effect and seriousness of the problem arises from the mud reducing the permeability of the productive horizon rather than the possibility of a blowout or continued loss of circulation. In general, the loss of circulation problem in Worland is not as serious as that in many fields in the Rocky Mountain area.

Two completion patterns have been used at Worland: the 7-in. oil string has been set in the top of the Embar with open hole below the pipe; or the pipe set through the pay and gun

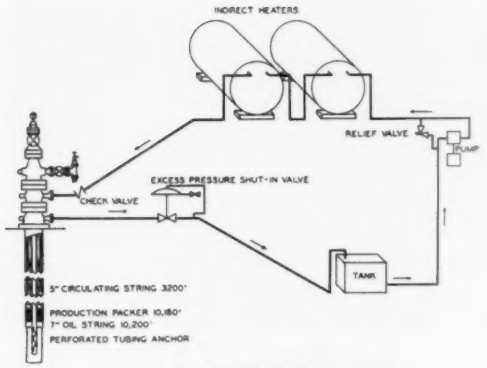

FIG. 1 — HOT OIL CIRCULATING SYSTEM.

perforated. Setting casing through the productive zone was done either to test zones below the Embar or in the belief that the gas/oil ratio might better be controlled through selective perforating. Wells high on the structure (Embar top at 5,900 to 6,200 ft subsea) had a tendency to produce oil with an API gravity of 37° to 45° with gas/oil ratio ranging from 5,000 to 18,000 cu ft per bbl. Lower wells on the structure (–6,200 to –6,402 ft) produced oil of API gravity ranging from 24° to 38° with gas/oil ratios of 1,500 to 4,500 cu ft per bbl. Production history indicated that the principle of selectively perforating the Embar zone did not materially affect the producing gas/oil ratio nor were any other advantages apparent. Consequently the majority of the wells were completed with the oil string set about two ft into the Embar limestone.

If a well did not produce by natural flow, it was swabbed in. Frequent failure of sand lines after coming in contact with sour well fluids led to the use of galvanized lines and treatment in a corrosion preventive organic compound bath. After the final pull of each day, the line was passed through the bath and laid out overnight rather than being spooled. The problem of the failure of sand lines and associated wire lines has been so serious that some service companies refuse to run their wire lines in any well producing sour fluids.

Acidizing has been very effective in increasing productivity of wells. The usual treatments were an initial 5,000 gal of 15 per cent hydrochloric acid containing emulsion breaking, surface tension reducing, and corrosion inhibiting agents followed by a 15,000 gal treatment with the same type acid. These quantities are average values as some wells have been acidized with as much as 50,000 gal.

Hydrates

The most economical and efficient method of reducing hydrate formation in facilities carrying well fluids was through the application of heat. This was accomplished with the hot oil circulating system furnishing heat to the well tubing and with flow line heaters furnishing heat for the surface facilities.

Fig. 1 illustrates the hot oil circulating system. Electric motor-driven reciprocating or centrifugal pumps take suction from a surge tank and discharge through indirect heaters to the well head. As the temperature of the circulating oil is raised as high as 180°F, circulating lines are either buried or insulated. The hot oil transfers heat to the fluid being produced by circulation down the annulus between the 5-in. casing and the 2½-in. tubing and up the annulus between 5-in. and 7-in. casing. The temperature drop in the circulating system from the well inlet to outlet varies between 35° to 75°F.

To prevent high pressure well fluids from escaping through the circulating system in the event of tubing or packer failure, a check valve is installed on the circulating inlet line and an excess pressure shut-in valve is installed on the circulating outlet line. The shut-in valve remains closed until manually re-set after trouble has been corrected. All pipe and fittings, up to and including the check valve and shut-in valve, are capable of withstanding full well pressures.

The flow-line hook-up used during the first period of operation while producing into tank batteries is shown in Fig. 2. Tubing head pressure was reduced to first stage separation pressure through four adjustable chokes at the indirect flow heaters in order to maintain well fluid temperature above the hydrate point during three stage separation.

An excessive amount of breakage occurring in stems of well head valves was believed to be the result of a combination of hydrogen sulphide embrittlement, cold embrittlement, and hydrate formation around the stem. Stainless steel alloy valves were used in an attempt to alleviate this situation but some breakage of the alloy valves occurred. The cold weather procedure of applying heat from a portable steam generator to valves not frequently used, before attempting to open or close them, has further reduced this trouble.

Tank Batteries

To avoid transporting hazardous gas unnecessary distances, individual tank batteries were installed for most wells during the first period of operation.

The vapor system at Worland tank batteries was designed to prevent escape of toxic gases to the atmosphere; to reduce losses in oil gravity and volume by normally maintaining a 2-oz pressure in tanks; and to prevent air from entering tanks by maintaining a sweet gas blanket. Sweet gas was available for this and other requirements in that a district fuel gas system distributed gas purchased from a gas company's pipe line that traversed part of the field. The exclusion of air from tanks minimized the possibility of tank explosion from spontaneous ignition of iron sulphide in the tank.

This vapor system is illustrated in Fig. 3. The two-way valve on the vapor outlet from each tank was normally open to the main vent line which had a regulator to maintain a 2-oz back pressure. The sweet gas supply regulator set for approximately 1¾ oz fed gas into the main vent line when pressure was reduced below the venting pressure of 2 oz. The second line was a by-pass around the back pressure regulator from the tank to the flare.

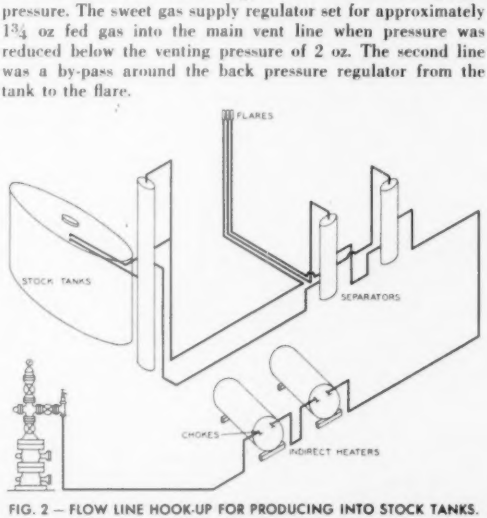

FIG. 2 — FLOW LINE HOOK-UP FOR PRODUCING INTO STOCK TANKS.

Before opening the thief hatch to gauge a tank, pressure in tank was reduced by operating the two-way valve lever which closed main vent line and opened the by-pass line. This isolated the tank and minimized the escape of vapor when the hatch was opened. The hatch cover cannot be lifted until the two-way valve is opened into the by-pass line. The proper operation of the system was checked by the manometer installed near the hatch.

The shop-made separator reduced gassing in the tanks by venting direct those vapors that came out of solution when pressure was reduced from the 50 psig second stage to the 2-oz. third stage separation. The shop-made separator was made from 20-in. pipe. From it the oil gravitated to the stock tank.

Additional precautions were taken to protect personnel around tank batteries. Tank walkways were provided with double stairways to permit exit from either end in an emergency. Field regulations demanded that whenever a person went on a tank walkway he must wear a gas-mask and that a second party equipped with a gas-mask remain at the fire wall. Consequently, in the event of an emergency, help was available immediately. The fresh air type mask was adopted and has proven satisfactory for all usage. Air is provided to the face piece through a reducing regulator from a high pressure cylinder that is mounted on a carrier and strapped to the back.

Two base mask units are assigned to each pick-up truck used by the switchers. Each man is furnished with a personal face piece. Every endeavor is made to safeguard personnel through the use of available equipment and safety instructions. Resuscitator units and facilities for recharging mask air cylinders are maintained at three locations in the field. Oxygen therapy units, gas masks, face pieces, cleaning solutions, and replacement filters are maintained at switchers' dog houses.

Tubing Failures

Failures of tubular goods in the Worland Field have caused a great deal of trouble and expense to the operators. The majority of failures have occurred in tubing couplings. These have varied from open breaks to lines of cleavage along the plane of the tubing. As many as eight specific breaks have been found in one string of tubing; however, tubular failures have not been entirely limited to tubing as five coupling breaks occurred when a five-in. circulating string parted. Several breaks have occurred in flow lines from wells to heaters where tubing is used. Repeated laboratory investigations of broken pipe have failed to reveal active corrosion.

No definite conclusions have been drawn as to the cause of these breaks. However, the combination of thermal stress induced by the circulating system operation, and hydrogen embrittlement cannot be disregarded as a possible cause.

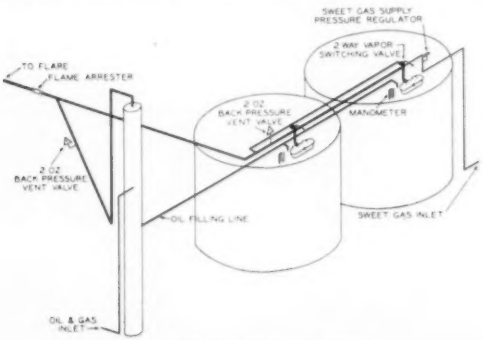

FIG. 3 — TANK BATTERY VAPOR SYSTEM.

FIG. 4 — WORLAND GASOLINE PLANT NO. 21.

GASOLINE PLANT

An agreement was reached between The Pure Oil Co. and the Texas Gulf Sulphur Co. whereby Pure would deliver the sour gas produced from the Embar reservoir to a plant to be constructed and operated by TGS for recovery of commercially pure sulphur from the hydrogen sulphide. The sweetened gas would be returned to a conventional absorption plant to be built and operated by Pure for recovery of natural gasoline and LPG's. An agreement was reached with the Montana Dakota Utilities Co. for the purchase of available residue gas. A 12-in. gas transmission line to Baker, Montana, is nearly complete and Worland gas will soon be distributed to MDU's customers in Montana, North Dakota and South Dakota.

The Worland Gasoline Plant (Fig. 4) is a conventional absorption and fractionation plant designed to process without modification 30 MMcf of sweet Embar gas per day and recover 70 per cent of the propanes, 95 per cent of the butanes, and all of the pentanes plus. The high and low pressure sweet gas streams returned from the TGS plant are processed directly in the 250 psig or 60 psig absorbers. Also, capacity has been provided to process the sweet Frontier gas direct from separators located at the terminus of the Frontier gathering system in the plant area.

The crude stabilization section of the plant serves the threefold purpose of removing hydrogen sulphide from the oil leaving essentially sweet crude; of recovering as liquid hydrocarbons those light ends that would normally be lost in atmospheric storage; and of treating oil to pipe line specifications. The stabilized crude is run to central storage facilities adjacent to the plant from where it is transported through pipe lines to refining centers.

With an approximate daily average production of 30 MMcf of sour gas, 320 long tons of sulphur, 10,000 gal of propane, 8,500 gal of butane, and 12,000 gal of 26-lb natural gasoline are recovered from the two plants.

The jointly owned water system installed by Pure to provide cooling and boiler feed water for the gasoline and sulphur plants consists of an intake station at the river where three turbine-type centrifugal pumps, driven by electric motors, deliver water into a 38-in. buried steel line (externally coated and wrapped and cathodically protected) to the vicinity of the plants. There the stream splits into a 30-in. line to the sulphur plant and a 28-in. line to the gasoline plant. Quantity of water pumped is sufficient to maintain temperature below the temporary hardness point, and velocity of flow is sufficiently high to prevent sand and silt from settling out of the

extremely turbid water in any part of the cycle. Open coil coolers were selected to avoid trouble from silt plugging.

The warm water from both plants returns to the river in an open ditch paralleling the 38-in. intake line. Provision is made near the river to direct the return water either immediately upstream or downstream or into the intake station pit. Any combination of the three may also be used. In winter, the return water is directed both upstream and into the intake pit to prevent station from freezing.

EMBAR GATHERING SYSTEM

The major change in producing operations upon completion of the plants was that oil was no longer recovered in tank batteries. Instead, wells were produced directly into a gathering system operating at 325 psig which delivered oil and gas together in a common line to the separators located at the plant (see Fig. 5). The line was laid to grade to minimize liquid accumulations and consequent uneven gas volume delivery to the plant. Winter subsurface temperature surveys indicated the desirability of burying lines with a minimum of five ft coverage so that additional heaters would not be required to prevent hydrate formation in the system.

The gathering system of all welded construction was designed for a pressure drop of five psig per mile when either the east or the west leg of the system was conducting a sufficient quantity of gas and oil to load the plant. This resulted in a main line sizes varying from 5½ in. to 16 in. in diameter. Pipe in the system is coated, wrapped and cathodically protected.

Trouble with hydrate plugging has been encountered in sections of the main line and lateral lines not being used when block valve leaks permit gas to accumulate in the dead sections. This problem apparently cannot be eliminated unless positive shutoffs can be obtained with the valves.

Safety devices employed for the gathering system include pilot operated valves to shut-in each individual well in event

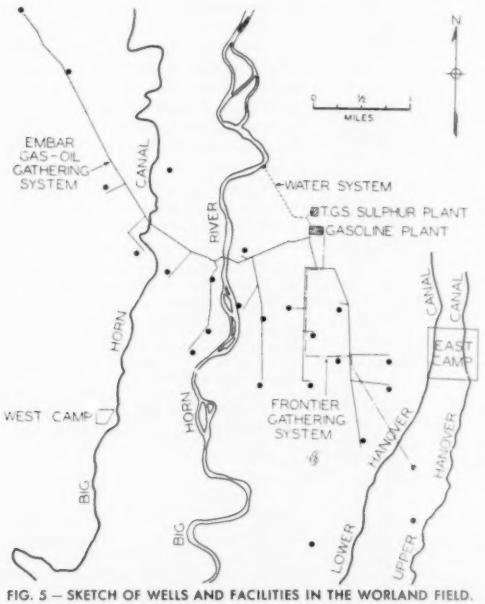

FIG. 5 — SKETCH OF WELLS AND FACILITIES IN THE WORLAND FIELD.

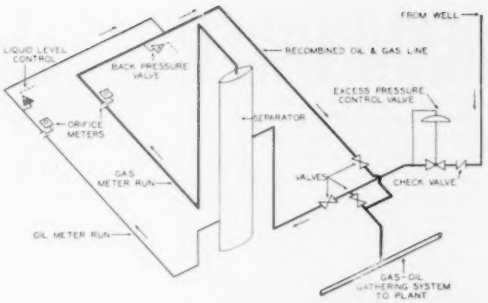

FIG. 6 — HOOK-UP TO METER INDIVIDUAL WELL PRODUCTION.

of excess pressure in gathering system, and a pressure relief valve set at 400 psig in each leg of the system. Check valves are installed at each well to prevent backflow to the well.

So that individual well production could be determined, flow lines from the well were connected for direct flow to the gathering system or for flow through the separator, meter runs, recombined line and into the gathering system as shown in Fig. 6.

UNITIZATION

During the first period of operation four operators — Pure, Trigood, Sharples and Carter — partially developed their lease and were obligated to drill and produce offset wells that were not structurally located to recover oil at the lowest gas/oil ratio. The various operators soon realized that unitization was the only solution to permit selective production of the field for maximum oil recovery. Consent was obtained from all working interest and royalty owners and working agreements permitting total unitized operation of the field and gasoline plant with Pure as operator became effective May 1, 1950.

Since unitization, daily production from the field has been restricted to that quantity of oil which can be produced with the 30 MMcf of gas the sulphur plant is capable of processing. Thus, withdrawals from the reservoir are all utilized in producing marketable products.

FRONTIER DEVELOPMENT

In order to bring the residue sweet gas sales to contract volumes, three high gas/oil ratio wells of the Embar zone have been recompleted in the Frontier (Cretaceous). The Embar was sealed off with cement plugs and the Frontier zone was perforated for production.

Early production tests on a recompleted well showed hydrates forming in the tubing; therefore, the hot oil circulating systems were retained to be used in producing Frontier wells. Flow line heaters in the vicinity of the wells maintain gas temperatures above the hydrate point.

Hydrogen sulphide is not present with fluids from the Frontier formation, so this gas need not be processed by the sulphur plant. A Frontier gathering system (See Fig. 5) with line sizes varying from 6 in. to 10 in. in diameter was constructed to conduct fluids from wells to a stage separation battery at the gasoline plant. Gas streams are processed in the plant high and low pressure absorbers. Condensate is moved to a Frontier storage area adjacent to the Embar storage area.

CONCLUSION

It is believed the successful development of the Worland Field is another indication of the progress being made by the petroleum industry to produce hydrocarbon products to meet the nation's civilian and military requirements. ★ ★ ★

MANPOWER —THE MOST IMPORTANT FACTOR IN DEFENSE MOBILIZATION

By E. W. Berlin

Standard-Vacuum Oil Co., Member AIME

Manpower — the most important factor in defense mobilization.

There are two important phases to be considered. One, manpower to implement essential defense industrial production; and two, that required to man our war machines.

In times of all-out mobilization, as well as in the present partial mobilization, it is difficult to establish an equitable division of manpower between the two phases cited. Impartial recognition of the importance of each phase is most difficult to attain. The result is competition for manpower by industry and the military, necessitating the establishment of government agencies for control. Due to the complex governmental establishment, overlapping authorities arise in the field of manpower control. At present the Office of Defense Mobilization is the top authority on manpower.

Industry says, "How can we be expected to operate at the high level of efficiency required to produce military and essential civilian needs if you call our experienced technical labor into the armed forces."

The military establishment says, "Our directives require X number of men qualified in the art of waging effective war. They must be made available."

Both industry and the defense department are right. When the supply of qualified manpower is not sufficient, the division of that manpower must be made on an equitable basis. It has been well said that the success of any endeavor is largely due to the human qualifications of the people involved. It would surely be courting disaster to man a fine luxury liner with mentally deficient inexperienced staff and operating personnel. The same principle applies to industrial plants as well as battleships, aircraft, and other essential war equipment.

The petroleum industry recognizes its responsibility to the Department of Defense with respect to the requirements of the armed forces for petroleum personnel who are qualified by reason of technical training and experience to handle petroleum matters. This has been attested both by the industry's willing participation in the establishment of petroleum-type reserve units affiliated with individual companies and by the cooperation of the industry with the armed forces in providing field training for regular officer personnel in the various phases of petroleum operations and administration. The petroleum industry further recognizes the importance of being prepared to meet emergency demands which a total war would entail.

This report has been prepared on the basis and in the firm belief that a workable balance between the requirements and interests of the armed forces and of the petroleum industry is possible and essential under partial as well as total mobilization.

It is important to note that there are 200 times as many reserve officers employed by the petroleum industry at the present time as there were in 1941 at the entrance of the United States into World War II, whereas there has been only a 30 per cent increase in employment generally in the petroleum industry in the last ten years. Such a comparison in itself is evidence of the increased impact which total mobilization would have upon the petroleum industry as compared with the mobilization which resulted after Pearl Harbor.

The petroleum industry does not seek preferential treatment over other essential industries with respect to the requirements of the armed forces for manpower. It is suggested that each oil company conduct a careful and detailed survey of their manpower problem and make an earnest effort to release reserve officers and enlisted personnel, if called, who are not absolutely essential to operations.

It is suggested that each company make up a report on essentiality and replacement of employes subject to military service who are male U. S. citizens between the ages of 18½-26 years inclusive, or reservists regardless of age or sex, on the form on Page 19.

A discussion of manpower problems must necessarily be approached from two directions—selectees and reservists.

SELECTEES

Present Partial Mobilization

With the current age bracket of 18½ to 26 established for the induction of selectees into the armed forces, only exceptional cases should be considered for deferment. In such cases, utilizing a Table of Essentiality and Replacement as a guide, the company should address a letter to the individual's draft board, outlining the facts substantiating the request for deferment, and requesting consideration of the company's position when the individual is classified. If the request is granted, the company should still proceed with plans for

ABOUT THE AUTHOR

E. W. Berlin, aside from being chairman of the AIME Production Review Committee, is:

Chairman, API Defense Services Committee

Member, National Petroleum Council's Manpower Committee

Colonel, U. S. Air Force Reserve

TO AIME MEMBERS

On Aug. 16, 1950, the AIME Executive and Finance Committees, meeting in joint session, authorized the following procedure:

When a member is inducted into military service, he is offered temporary suspension from AIME membership until he re-enters professional work. No membership fees will be charged and no usual privileges will be extended, but the member's original membership election date will be preserved. He will be entitled to any credits that may be authorized on initiation fees for continuous dues-paying membership. Upon induction, a member should immediately notify the Secretary at 29 W. 39th St., New York. Each request for such procedure by a member will be handled on an individual basis by the AIME Executive Committee.

THE MILITARY AND INDUSTRY ARE VYING FOR THE BRAINS OF THE NATION. HERE, A MAN OF HIGH RANK IN BOTH CAMPS GIVES HIS VIEWS ON WHAT SHOULD BE DONE TO CONSERVE MANPOWER.

training or procuring a replacement, as the individual is still subject to reclassification and induction. There is no provision for blanket deferments, nor is one anticipated.

All-Out Mobilization

In the event of all-out mobilization, the age bracket for selectees will probably be expanded by amendment of the Selective Service Act to include selectees through 36 years of age, or some age in that general area, and this will have a critical impact on industry. Should this happen, it is suggested that all units of industry review their employes in the expanded age bracket as soon as Congress has acted, using a Table of Essentiality and Replacement as a guide, and determine those individuals for whom deferment must be requested to maintain the minimum level of effective operations. A letter containing facts substantiating a deferment request for each individual concerned should then be sent to the appropriate draft board without waiting for these individuals to receive their draft call.

It is hoped that P.A.D. manpower section will be functioning long before an all-out mobilization is likely to be ordered, in which case the official sanction of this government agency in supporting requests for deferment of selectees should result in the protection of essential industry's manpower. When this P.A.D. manpower section is functioning, the requests for deferment of selectees should be cleared through P.A.D. for their official approval, as was the established procedure with P.A.W. in World War II.

RESERVE PERSONNEL

Partial Mobilization

Affiliated reserve units with the petroleum industry, sponsored by the oil industry, are available for duty with the armed forces on short notice as integrated units. Therefore the personnel within them are *not subject to deferments* and will be called only when the unit is ordered to active duty.

In the case of reserve personnel not assigned to affiliated units, the sole responsibility for granting delays in recall to active duty rests with the Department of Defense, and more specifically with each service in the department. The responsibility of each service is further delegated to the six Army Areas, the numbered Air Forces, the Naval Districts, and to the authorized order-issuing agency for the Marine Corps. There are established department reviewing boards for cases where appeals are made over the findings of the local reviewing board.

It is of utmost importance that all units of industry study carefully and follow instructions issued in Army Regulations No. 135-230, dated Washington, D. C., September 7, 1950. These regulations are available at all military installations or can be had on request from the Department of the Army. Comparable regulations for the other services have been requested but have not yet been obtained.

The various services are conscientiously trying to meet the present requirements of the Defense Department without causing too much dislocation within essential industries. The impression gained is that the personnel sections of all services are doing a very good job of screening personnel in the reserve with regard to dependents and the personal problems of each individual considered. But as they state, the industrial implications have not in all cases had as careful a review as they might warrant; not through the fault of the services but just because they are not adequately informed by industry. The Navy's most recent classification questionnaire requires a statement by each reservist based on consultation between him and his employer as to the period of time within which he will be available after call.

Pending some definite improvement in the present machinery for the selection of reservists for active duty, it is highly important that industry assume the responsibility of advising the services in advance regarding the importance to industry of essential personnel who are reservists.

This important information should be prepared in letter form on each such reservist in order that the Defense Department's records on the individual be complete. The form on Page 20 is suggested. These letters of essentiality should be sent to the personnel section of the organization to which the individual reports, with a duplicate to the Adjutant General, Personnel Section, Washington, D. C., for the Army; to the Bureau of Personnel,

Report on Essentiality and Replacement of Employes Subject to Military Service Who Are Male U. S. Citizens Between Ages of 18½ and 26 Years Inclusive, or Reservists Regardless of Age or Sex

CODE				CODE	MILITARY SERVICE STATUS			
					Reservist		Non-Reservist	
Essentiality	Dept.	Name of Employe	Job Title	Replacement	Under 26	26 or Over	Vet.	Non-Vet.

CODE OF ESSENTIALITY

1 Impossible to replace effectively — Key Man
2 More than one year required to replace effectively — Key Man
3-A Between 6 - 12 months required for effective replacement
3-B Up to 6 months required for effective replacement
4 Readily replaceable by hiring, transfer, combining duties, etc.
5 Replacement not a problem

CODE OF REPLACEMENT PROCEDURE

1 Impossible to replace effectively within any specified time limit
2 Replacement must come from within organization
3 Replacement can be effected by outside hiring or transfer
4 Would not replace — job would be combined
5 Would not replace — job would be discontinued

Navy Department, Washington, D. C., for the Navy; to the Air Adjutant General, Personnel Section, U. S. Air Force, U.S.A.F. Hq., Bolling Field, Washington, D. C., for the Air Force; and to the Adjutant General, Personnel Section, U.S.M.C., Washington, D. C., for the Marine Corps, with information copies to Petroleum Administration for Defense, Manpower Section, and Munitions Board Petroleum Division, Plans Branch. This information should be prepared and presented by the company or employer. These letters containing information regarding each reservist's essentiality to critical industry should be placed in the individual's file, thus allowing the service to review this information at the time the reservist is considered for call to active duty. Letters should be kept current with changes in status of the individuals reported on.

Under Item 2 of information furnished by employer on the suggested form, the employer should give employe's responsibility and experience fully. It is further suggested that the Department of Labor Dictionary of Occupational Titles and Occupational Classifications be used in completing job descriptions where applicable. The dictionary can be obtained from the Government Printing Office.

All-Out Mobilization

The prevailing conditions, unless some changes in policy can be effected before all-out mobilization is ordered, will provoke a critical personnel problem due to the much larger number of reservists now compared to the period prior to World War II. In addition, the reservists represent the most vulnerable segment of manpower, as the fact that they have continued to hold reserve commissions is proof of their willingness to serve their country. Also there is the possibility that all officers who served in World War II in the Army of the United States can be recalled to active duty whether or not they accepted reserve commissions at the time of their release from active duty. It is industry's responsibility to present its case for maintaining essential manpower in cases where the individual's contribution to the national defense may be more important in essential industry than in the Defense Department.

The petroleum industry, like many others, is classified as an essential defense industry and has a responsibility to the Defense Department to supply essential material for national defense. In order to do this, experienced key personnel must be maintained in industry.

Date _____ 19__

A. CIVILIAN INFORMATION

1. Name of Employe _____ (Last) (Middle) (First)
2. Age _____ years. 3. Sex _____ (M or F) 4. Natural Citizen _____ (Yes or No)
5. Number of Dependents a. _____ Age a. _____ Sex a. _____
   b. _____ b. _____ b. _____
   c. _____ c. _____ c. _____
   d. _____ d. _____ d. _____
6. Employe's Residence Address _____ (Number and Street) (City) (State)
7. Employe's Permanent Address _____ (Number and Street) (City) (State)
8. Employe's Business Address _____ (Number and Street) (City) (State)

INFORMATION BELOW TO BE FURNISHED BY EMPLOYER

1. Employe's (a) Occupation _____ (b) Length of Service _____
2. Give in **detail** employe's work. (Give record for past 5 years stating positions held, length of time in each and degree of responsibility.)

3. Degree of essentiality to employer
   a. Replaceable in _____ months
   b. Replaceable in 12 months
   c. Replaceable in 3 months
   d. Replaceable in 1 month
4. College or Technical Education of Employe
5. Employer
6. Business or type of work of employer
7. Employer's Address _____ (Number and Street) (City) (State)
8. Remarks
9. Employer's Certification: I certify the above is correct to the best of my knowledge and belief. Signed by _____ Title _____

B. MILITARY INFORMATION

1. Name _____ (Last) (Middle) (First)
2. Serial No. 3. Present grade or rank
4. Service: Air Force, Army, Marine, Navy, N. G., Air N. G., C. G.
5. Reserve (a) _____ (Yes) (No) (b) _____ (Active) (Inactive)
6. Unit Assignment or Mobilization Designation
7. Unit Address
8. Last military duty:
   (a) Type or kind of work
   (b) Time in this work _____ Years _____ Months
   (c) Months in Armed Services in Active Duty _____ Months; in Reserve _____ Months
   (d) Total time overseas _____ Years _____ Months
9. M.O.S. (Military Occupational Specialty), if known
10. Service Schools attended or course completed:
    (a)
    (b)
    (c)
11. Physical Status (Present):
    (a) General _____ Service
    (b) Limited _____ Service
12. (a) I am (am not) drawing disability returns from a Federal agency _____ Dollars _____ Months or Years.
    (b) If drawing disability returns I will (will not) waive compensation in case of induction.
13. Remarks

To the best of my knowledge, this is a true and correct statement:
(Signed) _____
(Printed) _____

1st Endorsement _____

Under emergency laws reservists who are in key positions cannot resign their commissions. The experience of successful executives and technicians is needed in the services in time of emergency as well as in industry. There must therefore ultimately be a policy established by the appropriate agencies of the Federal government which will give an equitable balance between competent, experienced technicians and executives serving with the Defense Department and those remaining in key positions in industry to carry out the functions of this essential industry in time of emergency. The implementation of such a policy will require the wholehearted cooperation of industry in making available detailed information on the essentiality of the individual reservists in its employ.

Battleships, planes and tanks without properly trained efficient men are not weapons; they are also useless without fuel to propel them.

SUMMARY

1. With the age bracket for selectees now set at 18½ to 26 years, the impact on industry should not be of consequence except in very exceptional cases which should be covered by letters to draft boards in question.

2. P.A.D. plans to include manpower agencies which will act as claimant

Continued on Page 7, Section 2

Primary Cementing Practices

A North Texas Section Report

The Southwestern District of the API, at its spring meeting in Dallas last year, decided to form a study committee to investigate primary cementing. The purposes of the study were to determine industry practices, the factors contributing to cementing failures, and if possible, the effectiveness of the different methods used.

Chairman of the investigating committee was Louis F. Davis of The Atlantic Refining Co. Last month Davis revealed the results of that survey before a meeting of the North Texas Section of the AIME.

Information cards were requested on all wells drilled during the last half of 1950. By last month, 1,514 cards were in from 28 companies. Many cards were received too late for inclusion in the study and some contained insufficient data. Therefore, only 1,176 cards were used in the analysis. Cards were received on fields located in the Gulf Coast area, Central Texas, North Louisiana, Arkansas, Mississippi, West Texas and New Mexico.

In order to guide the engineers who were making the analysis, the committee set up rules for determining the quality of cement jobs. Wells meeting the following conditions were to be classified as having good primary cementing jobs:

1. No water production, normal gas/oil ratio, no precautionary squeezing or remedial work.
2. Water production or abnormal gas/oil ratio, with water or gas present within the producing zone, with no remedial work being performed.

Wells meeting the following conditions were to be classified as having bad primary cement jobs:

1. Water production or abnormal gas/oil ratio, where there was no water or gas within the producing formation.
2. Water production or abnormal gas/oil ratio where remedial work achieved marked reduction of water or gas production.

Wells not meeting the conditions for a good or bad classification were considered indeterminate and were classified as "other."

It has long been recognized, Davis said, that the nature of formations drilled has a very considerable effect upon cement jobs. Accordingly, the cards were divided into three general areas. These areas are West Texas and New Mexico; Central Texas, Arkansas, Mississippi and North Louisiana; and the Gulf Coast area.

An early examination of the data showed a pronounced lack of trouble in the West Texas area and the Central Texas area. In West Texas, there were only four bad cement jobs out of a total of 390, and in the Central area, there were only four bad jobs out of 256.

It is believed that this is principally due to the nature of the formations penetrated. Compared to the Gulf Coast, the formations are hard, well consolidated, and impermeable, and holes stay close to gauge. Filter cake is not the problem that it is on the Gulf Coast. There are usually no abnormal pressures encountered and mud weights need not be heavy. Also, many open hole completions are made, in which case all the cement job has to do is seal around the bottom of the casing. The producing formations are usually fairly thick and not too close together.

LOUIS F. DAVIS

In the Gulf Coast area natural mud gave the best results. This can be explained by the fact that of the 71 wells on which natural mud was used, 36 were from 0 to 4,000 ft, 19 were from 4,000 ft to 6,000 ft, and 16 were from 6,000 ft to 8,000 ft in casing setting depth. Most of the shallow wells drilled in the Gulf Coast area used natural muds and the high percentage of success is believed due not to the muds as much as to the general well conditions. The same thing cannot be said of the oil emulsion mud. It was used in a variety of applications and gave uniformly good results.

In Table I, the numbers on muds 16 lbs and over are not being considered as statistically having much weight, since there were so few of these jobs. It is difficult to explain the lower success percentage of 90.8 on muds from 11.1 to 12 lbs. This anomaly is believed not associated with the mud weight but brought about by some other factors that will appear later in the analysis. The viscosity of the mud shows a very discernible trend, and the cement jobs become progressively better as the viscosity of the mud increases.

In the section on water loss, for muds with water losses under 10 cu cm the percentage of success is much higher than those of 10 cu cm and over. With a high water loss there is a thick cake opposite permeable formations which one would expect to interfere with a satisfactory cement job. The next section of data on filter cake confirms the conclusions made from the water loss data. Results are much better where the cake is under 5/64. The four wells where the cake was over 5/32 all used scratchers, centralizers, and two plugs.

Section B gives data on the mechanical aspects of cementing. It is noteworthy that centralizers and scratchers are very widely used and that together

they give excellent results. Where scratchers are used alone the results are poor.

On annular space clearance it will be noted that a small clearance does not give good results nor does the use of too large a hole, and that the highest success ratio is secured where the clearance is between $1\frac{7}{8}$ in. and $3\frac{3}{4}$ in.

The section on plugs indicates that the use of the two plug system is now wide-spread. The fact that better success was achieved when using only one plug was an unexpected result and the data were further analyzed in an effort to determine the factors contributing to this result. The only significant factor found was that one plug was used in 40 of the 55 good jobs in the 0 - 4,000 ft depth category, where no failures occurred. This is not sufficient to explain the superior performance of one plug for when all wells shallower than 4,000 ft are excluded, the success using one plug is 95.4 per cent vs 92.1 per cent using two plugs.

The data on staging tools in the Gulf Coast are probably not significant. In each of the three failures shown the completion interval was 1,500 ft or more below the stage tool so that the staging should have had no influence upon the primary cement job.

The depth the casing is set shows a definite trend. The shallow wells give little trouble and the deeper one goes the more difficulties are experienced. An inconsistency is the 97.7 per cent success found in the depth interval from 8,000 ft to 10,000 ft. It will be noted, however, that a larger proportion of the jobs in this interval was classified as "other." Analysis of these 47 other jobs shows that 35 of them had precautionary squeeze jobs or squeeze jobs within 50 ft of the completion interval. It is reasonably certain that some additional failures would have occurred in this depth interval had more completion attempts been made without resort to precautionary squeezing.

On the distance between the float shoe and float coupling there is no significant relationship. On the distance the producing interval is above the casing shoe there is found a general trend that the further completion is from the shoe, the less success. However, this is contradicted by the section between 150 ft and 200 ft. The jobs falling in this classification were analyzed to determine the presence or absence of factors which might offer an explanation of the anomaly, but none were found. The limited amount of data and the influence of chance are perhaps responsible.

Continued on Page 7, Section 2

Table I — Gulf Coast Area Statistical Data on Primary Cementing

	JOB CLASSIFICATION						
	GOOD		BAD		OTHERS		Per Cent
	No.	Per Cent	No.	Per Cent	No.	Total	of Total
A. MUD CHARACTERISTICS							
1. Types							
Lime or Lime Impermex	59	92.2	5	7.8	29	93	17.7
Oil Emulsion	34	97.1	1	2.9	18	53	10.1
Fuospnate	138	94.2	10	6.8	31	179	34.1
Natural	71	98.6	1	1.4	8	80	15.3
Alkaline Tannate below 10.5 *pH*	48	92.3	4	7.7	10	62	11.8
Alkaline Tannate above 10.5 *pH*	18	94.7	1	5.3	19	38	7.2
All Other Mud Types	9	81.8	2	18.2	9	20	3.8
						525	
2. Weight							
9 - 10	55	96.5	2	3.5	6	63	11.9
10.1 - 11	195	94.2	12	5.8	66	273	51.6
11.1 - 12	69	90.8	7	9.2	41	117	22.2
12.1 - 14	36	97.3	1	2.7	10	47	8.9
14.1 - 16	19	95.0	1	5.0	1	21	4.0
16.1 - Over	5	83.3	1	16.7	2	8	1.5
						529	
3. Viscosity							
0 - 30	2	33.3	1	66.7	3	6	1.1
31 - 40	80	93.0	6	7.0	13	99	18.8
41 - 50	224	93.7	15	6.3	87	326	61.9
51 - 60	55	96.5	2	3.5	17	74	14.0
Over 60	17	100.0	0	0.0	5	22	4.2
						527	
4. Water Loss							
0 - 5	55	94.8	3	5.2	25	83	18.7
5.1 - 10	224	94.5	13	5.5	79	316	71.0
10.1 - 15	20	83.3	4	16.7	10	34	7.6
15.1 - Over	10	90.9	1	9.1	1	12	2.7
						445	
5. Filter Cake							
0 - 5/64	201	94.4	12	5.6	86	299	81.0
3/32 - 9/64	43	87.8	6	12.2	16	65	17.6
5/32 - Over	4	100.0	0	0.0	1	5	1.4
						369	
B. MECHANICAL DATA							
1. Cementing Aids							
Centralizers Only	22	91.7	2	8.3	13	37	7.0
Centralizers and Stroking	12	85.7	2	14.3	4	18	3.4
Centralizers and Scratchers	286	96.0	12	4.0	49	347	65.5
Scratchers Only	22	81.5	5	18.5	2	29	5.4
Others	37	92.5	3	7.5	59	99	18.7
						530	
2. Hole Dia. minus Casing Dia.							
0 - 1⅞ in.	8	80.0	2	20.0	7	17	3.2
1⅞ in. - 3¾ in.	270	95.1	14	4.9	99	383	72.3
3¾ in. - Over	101	92.7	8	7.3	21	130	24.5
						530	
3. Plugs							
Used Ahead of Cement	213	92.2	18	7.8	67	298	56.2
Not Used Ahead of Cement	166	96.5	6	3.5	60	232	43.8
						530	
4. Stage Tools							
Yes	10	76.9	3	23.1	23	36	6.8
No	369	94.6	21	5.4	104	494	93.2
						530	
5. Depth Casing Set							
0 - 4,000	46	100.0	0	0.0	9	55	10.4
4,001 - 6,000	70	90.9	7	9.1	16	93	17.5
6,001 - 8,000	129	94.2	8	5.8	23	160	30.2
8,001 - 10,000	84	97.7	2	2.3	47	133	25.1
10,001 - 12,000	37	90.2	4	9.8	25	66	12.5
12,001 - Over	13	81.2	3	18.8	7	23	4.3
						530	
6. Distance Between Float Shoe and Float Coupling							
40 ft. or less	218	96.0	9	4.0	47	274	58.2
More than 40 ft	116	95.1	6	4.9	75	197	41.8
						471	
7. Distance Producing Interval Above Casing Shoe							
0 - 25	35	97.2	1	2.8	4	40	8.1
26 - 50	60	100.0	0	0.0	10	70	14.2
51 - 100	100	93.5	7	6.5	31	138	28.0
101 - 150	45	91.8	4	8.2	11	60	12.2
151 - 200	18	100.0	0	0.0	6	24	4.9
201 - 300	29	90.9	2	9.1	8	39	6.1
301 - 500	30	85.7	5	14.3	11	46	9.3
Over 500	45	90.0	5	10.0	35	85	17.2
						493	
C. CEMENTING DATA							
1. Slurry Weight							
0 - 14.9	73	98.6	1	1.4	15	89	18.8
15 - 16	251	93.0	19	7.0	102	372	78.5
Over 16	7	100.0	0	0.0	6	13	2.7
						474	
2. Wash							
Used	38	88.4	5	11.6	1	44	8.3
Not Used	341	94.7	19	5.3	126	486	91.7
						530	
3. Placement Velocity — Ft./Sec							
0 - 2	50	98.0	1	2.0	19	70	20.6
2.01 - 5	121	92.4	10	7.6	51	182	53.5
Over 5	65	92.9	5	7.1	18	88	25.9
						340	
4. Additives							
Yes	122	94.6	7	5.4	12	141	26.6
No	257	93.8	17	6.2	115	389	73.4
						530	
TOTAL JOBS	379	94.0	24	6.0	197		

Oil Field Corrosion–Practical Treatment and Cure

Reported by D. B. O'Neill
Pacific Junior Group

An open meeting of the Junior Section of the Pacific Petroleum Chapter last month heard a five-man panel of corrosion experts probe into oil field corrosion problems and discuss possible treatments and cures.

Seated about the panel table were Warren E. Woodruff, moderator and president of Technical Service, Inc.; William W. Messick, Standard Oil Co. of California; Sam Warren, Liquid Plastics Co.; John R. Brown, chief corrosion engineer for Kobe, Inc.; and William M. Baker, retired chief electrician for General Petroleum Corp.

Woodruff made a few introductory remarks regarding the general subject of corrosion and its application to the petroleum industry, pointing out that corrosion wasn't a serious problem as little as ten years ago inasmuch as materials then were much more expendable than today, and could be replaced easily. However, within the last five years especially, the oil industry has realized the importance of corrosion control. Woodruff said it is gratifying to see that the larger companies are now willing to make the expenditures needed to develop the technical aspects of the problem which are required to reach the desired goal.

He said that the man in the field had been one of the leading proponents in recognizing the need for corrosion control and that, consequently, it provided an excellent chance for industry men to combine technical knowledge with the practical aspects and work as a team in resolving the problem of corrosion. In essence, Woodruff said, corrosion and its control is a matter of dollars and cents, yet it is still an intangible thing which, at times, is hard to justify on an economic basis.

In analyzing briefly the results of the discussion, several important aspects of corrosion become evident. First, oil well corrosion is caused by two types of electro-chemical action which can occur separately or at the same time. These are acid attack and galvanic action. In addition, corrosion by micro-organisms (not only such anaerobic micro-organisms as sulphate-reducing, nitrate-reducing and methane-producing bacteria, but also various aerobic micro-organisms), has long been recognized. One general question was to distinguish between corrosion and abrasion. It was pointed out by several of the speakers that corrosion engineers define corrosion as the destruction of metal by chemical or electrochemical reaction of the metal with its environment. Corrosion may also be caused by electrolysis (the production of a chemical change in an electrolyte resulting from the passage of electricity) due to some extraneous currents, or may be accelerated by abrasion.

One of the more enlightening points of the evening was a discussion of the effect of drilling fluids on oil well casing. This was handled by a member of the audience, Al Morrison of Shell Oil Co., inasmuch as that company has recently concluded a series of experiments on this subject. Morrison pointed out that, during the period from 1942 to 1948, a number of wells were drilled in the Ventura Avenue Field in California, using mud with low *pH* values in which, it is known, bacteria will thrive. Within a short period of time, a number of wells drilled with the low *pH* muds developed serious casing failures which resulted in excessive remedial expense. A chemical analysis of the corrosion products on some of the recovered corroded casing from these wells, revealed the principal cause to be sulfate-reducing bacteria. The generally accepted limits for bacterial activity are *pH* 6 to 9.5, so it was decided to employ high *pH* muds (around 10-11) in future wells (*i.e.*, those drilled since 1948). Since doing this, no failures have occurred. Morrison pointed out that the casing failures appeared most rapidly in the third year after the casing was placed in the wells. That much time has elapsed in wells where the higher *pH* muds were used, without a failure to date.

The question was asked as to how dependable and how significant is iron determination on well fluids and is there a good correlation between iron count of the effluent from the well and the amount of corrosion. Messick pointed out that iron counts are successful only in some wells, but that in most cases metallic coupon tests proved to be more acceptable. He stated that the most dependable and significant correlation between the type of corrosion inhibitor and its relative value is, of course, the results it produces. If failures of rods and tubing are lessened and pump changes reduced, it can obviously be concluded that the method used is the right one — at best, a system of cut and try.

An interesting sidelight, from the

Continued on Page 7, Section 2

PANEL OF EXPERTS who discussed oil field corrosion problems in Los Angeles last month are, L to R, William M. Baker, Warren E. Woodruff, Sam Warren, John R. Brown and William W. Messick.

The Alberta Gas Situation

Reported by Ray A. Hancock
Pacific Petroleum Chapter

John F. Dodge, consulting petroleum engineer, discussing the "Alberta Gas Situation" before a luncheon meeting of the Pacific Petroleum Chapter in Los Angeles last month, explained that the area of the Province of Alberta is 163,382,400 acres and the geologic column ranges from the Cambrian to Recent. The Devonian through the Cretaceous beds are of primary interest insofar as gas and oil are concerned. To date, the major oil discoveries have been in the Devonian. Some condensate fields have been discovered in the Madison or Rundle formation which are of Mississippian age. Some minor heavy oil has been found in the Cretaceous.

The greatest number of gas discoveries have been in the Cretaceous, which is gas bearing over a large part of Alberta. The most important single gas field reserves are in the Madison, namely Pincher Creek, Jumping Pound, and Turner Valley, all of these being foothills structures along the front of the Rocky Mountains. Some recent discoveries, as at Whitelaw in the Triassic, may be of major importance. Minor discoveries have been found in the Jurassic Ribbon Sand in southeastern Alberta, as at Black Butte.

During the period 1940 to 1946 the emphasis on development of the gas fields was to provide a source of supply for synthesis plants to convert natural gas into motor fuel. Prior to this time development was for local use only. The Viking Field was discovered in 1914 and the adjacent Kinsella Field in 1940. In 1923, a gas line was built from Viking-Kinsella into Edmonton to supply gas for domestic and industrial purposes. The Jumping Pound Field was discovered in 1944 and the Pincher Creek Field in 1948-49. Gas in the Northwest Territory has been known for many years at Pouce Coupe and Peace River. Other areas where gas has been discovered include Normandville, Whitelaw, Blue Sky, and Valley View.

The discovery of oil at Leduc in February, 1947, and at Red Water in October, 1948, changed the direction of exploration and eliminated the need to synthesize gas for motor fuels, because these discoveries provided oil reserves large enough to insure an adequate supply of motor fuels.

Several gas reserve estimates have been made for Alberta. Among the various reports are those of the Dinning Commission, Hume, Nauss, Beach, and the Alberta Conservation Commission. In addition to these, several individual companies have made estimates. The estimates range from 4 to 6 trillion cu ft of gas, but do not include the recent developments in the Peace River country.

There have been several gas transmission line projects proposed, but to date no permits have been issued by the Provincial Government to export gas. The primary concern of the Alberta Government is to be sure that gas reserves are sufficient to insure an ample supply for Alberta for at least 30 years. Until they are satisfied on this point, there is little chance that export permits will be granted except possibly from gas fields so remote from centers of population that the building of pipe lines to supply Alberta consumers is considered uneconomic. Some of the gas transmission line projects which have been proposed are as follows: West into British Columbia, by the West Coast Transmission Co., the Northwest Natural Gas Co. and the Prairie Pipe Line Co., known as the Fish Project; East to the Great Lakes area, by the Western Pipe Line Co.; and South into Montana by the McCall Frontenac-Union-Montana Power Co. Two oil pipe lines have been proposed, one to the east by the Imperial Oil Co., constructed during the past year and now in operation, and one to the West by Frank McMahon and associated companies. An American group headed by the Bechtel Corp. has also been actively promoting a West Coast line.

The land ownership in Alberta is quite similar to that of California. Of the 163,382,400 acres, 13,434,000 acres have been set aside for national parks, 1,328,000 acres for Indian reservations and 16,000,000 acres are held in fee. The Province of Alberta retains the mineral rights on 132,620,000 acres of land. Prior to 1887 all government lands were under the Dominion Government and grants were made in fee. After 1887 the Dominion retained the mineral rights and in 1930, the Dominion transferred the jurisdiction of government lands to the provincial government of Alberta.

The Hudson Bay Co. was granted large tracts of land in the fertile belt, but in 1870 they returned to the Government all except 5 per cent of their grants. The area retained comprises all of every Section 8 and three-fourths of every Section 26 and they now have remaining 1,506,000 acres of land in Alberta between the Rocky Mountains and the eastern border. The Canadian Pacific Railroad was granted the odd numbered sections in all townships along the right-of-way except Sections No. 11 and 29. In the early days they sold much of this land without reservations, but still hold 7,266,000 acres plus 1,391,000 acres with coal rights only. The Calgary and Edmonton Corp. holds 1,350,000 acres of land. ★ ★ ★

Four Students Honored By Delta Section, LSU

The Delta Section and the AIME Student Chapter at Louisiana State University joined last month to stage a student paper competition at LSU. The program consisted of the four winning papers in the recent student competition among the seniors in LSU's Petroleum Engineering School.

Winner of a $35 first prize was A. H. Stephenson, author of the paper, "Properties and Applicability of High Early Strength Cement Plus Calcium Chloride." A second prize of $25 went to Jerry Bullock for his "Experimental Water Flooding." J. N. Rafidi was given a $15 third prize for his paper, "The Deviation Factor of Natural Gases," and Donald Olivier won a fourth prize of $10 for his paper, "A Study of a Gas Lift Installation in the Lapice Field."

Judging the papers were J. E. R. Sheeler, W. T. Ilfrey, Raymond Kelly and Al Vitter.

The judges congratulated the authors for presenting their work in an outstanding manner. ★ ★ ★

Oil Discovery Challenge of the Future

Reported by William E. LaRoche
East Texas Section

Members of the East Texas Section, AIME, and the Shreveport, La., Geological Society, meeting in joint session last month, were given the views of Warren L. Baker, editor of *World Oil*, on what the industry might expect in the way of a production challenge during the next ten years.

Baker pointed out that it is becoming decidedly more difficult to find oil in the United States. Large quantities of oil continue to be found in this country only because of a greatly accelerated effort.

Doubling of wildcat drilling rates since the war has found little, if any, more oil than found by half as many wildcats before the war. Despite the expanded search, fewer barrels of oil are being found in relationship to consuming and producing rates. Meanwhile, stepped-up wildcatting has burdened the industry with twice as many dry holes drilled annually, until failures now constitute more than one-third of all drilling operations.

A continuation of these trends forebodes trouble in the near future in keeping productivity abreast of skyrocketing consumption. With all signs indicating further sharp gains ahead in demand, it appears likely the industry will need to enlarge drilling far above current peak rates in coming years to find enough oil to provide sufficient producing ability to fulfill requirements. Present trends presage a necessity for drilling of 50,000 wells annually within five years and 56,000 wells within ten years. An even sharper growth in wildcatting is indicated, which would boost the number of dry holes drilled yearly.

A sharp growth has occurred in the principal oil-using units since the war.

The number of motor vehicles in use in the United States reached an all-time peak of 48.5 million at the end of 1950. Likewise, the number of farm tractors in use continues to increase.

At the same time, there has been an amazing growth in number of domestic or home oil burners installed. So far, contrary to expectations, the distribution of natural gas into many new areas has failed to retard the use of oil for home heating purposes. Displacement of coal and new home construction has permitted continued rapid growth of both oil and gas in the home heating field.

The most phenomenal growth in recent years has occurred in railroad diesel locomotives. Aside from terminal switch engines, not included in the figures shown here, very few main line diesel locomotives were in use prior to 1940. During the past year 3,000 additional main line locomotives went in operation, almost twice the annual growth previously.

Rapid dieselization of the nation's railroads is a very significant development for the oil industry. Because of their year-around use and large consumption, each diesel locomotive uses an average of about 5,000 bbl of distillate fuel oil per year. In contrast, during normal winters the average consumption per oil burner is less than 50 bbl and the average use per automobile is only 20 bbl.

United States use of petroleum has risen steadily every five years, and the increase in each succeeding five-year period has been slightly greater than in the preceding five years.

The five years since the war has experienced a larger growth than during the war period of 1940 to 1945. Consumption in 1950 was almost 1.5 million B/D greater than in 1945, whereas the gain between 1940 and 1945 was only a little more than 1.33 million B/D.

Growth of oil-using units presages that consumption will continue to expand at least as rapidly as in the past during the next ten years. United States demand for petroleum should reach at least 8.25 million B/D by 1955 and attain a minimum level of 9.75 million B/D by 1960. The latter rate would be approximately 3 million bbl or almost 50 per cent greater than in 1950.

Where is the oil going to come from to meet anticipated enlarged future consuming rates? The United States has three sources of raw supplies: imports of foreign oil, domestic production of natural gasoline and allied products, and domestic crude production. The postwar era has witnessed an especially sharp increase in imports, which in 1950 reached an average of 847,000 B/D. Imports in 1950 were almost three times greater than in 1945, and the rate of growth was six times that of the preceding ten-year period.

OKLAHOMA CITY SECTION OFFICERS elected for the 1951 term are, L to R, James C. Cordell of Stanolind Oil and Gas Co., vice-chairman; Joe Field of Sohio Petroleum Co., chairman; and Michael J. Popovich of Sohio, secretary and treasurer. Not pictured is Robert M. Caywood of Anderson-Prichard, vice-chairman.

With world crude production growing three times faster than United States output since the war, and with twice as much proved reserves existing outside this country than is held in the United States, imports of oil undoubtedly will continue to grow by substantial amounts in the future. For purposes of portraying a broad picture of the problem in the future, it may be assumed that they will almost double current rates and increase by 750,000 B/D to reach a volume of 1,600,000 B/D in 1955. Carrying this expansion trend a step further for the succeeding five years, imports may rise another million B/D to reach 2,600,000 B/D by 1960.

These future importation rates may seem high, but they have been deliberately set at what is expected to be maximum volumes. The purpose in doing this is to try to demonstrate what a man-size job confronts United States oil producers even if much of the future growth in demand is supplied by foreign oil. Of course, failure of imports to reach these volumes would only increase the burden on domestic production.

If imports reach the volumes suggested here, the United States must produce 6,000,000 bbl of crude daily by 1955 and 6,400,000 B/D by 1960.

It is significant to note that United States production of crude in 1950 reached 5,405,000 B/D, or 711,000 bbl more than in 1945. It is equally significant, however, to note that this rate of growth, despite its size, was less than in the preceding two five-year periods.

Because larger and larger quantities cannot continue to be found indefinitely, United States production of crude oil in the future likely will continue to grow by somewhat smaller volumes than in the past.

Every increase in production enlarges the need for finding larger volumes. The amounts already are so high, the industry may come to welcome a slowing down of production growth within the next few years unless there is a reversal in the country's discovery trends.

It is noteworthy that this country has continued to find large volumes of new oil each year. However, the large volume found since the war has not maintained the industry's prewar ratio with producing rates. Before the war, an average of 2 bbl were found for every barrel produced, but postwar discoveries have averaged only 1.6 bbl per barrel produced.

Back in 1938 when 3 million bbl of new oil were discovered, it was equivalent to 2.5 bbl for every barrel produced during the year. However, in 1948, when the larger volume of nearly 4 million bbl were found, it was equal to only 2 bbl for every barrel produced because production had increased so sharply. In 1950 more new oil was discovered or proven than in 1938, but the ratio to production was only 1.7 bbl compared with 2.5 in 1938. These figures point to the increased need for finding substantially larger volumes of oil when production rises.

Historical experience of the industry shows that we should find 1.8 bbl for every barrel produced to maintain our reserve position. So if the United States is to be producing 6,000,000 B/D by 1955, discovery rates must be increased sufficiently to average almost 4 billion bbl yearly by that time. If 1.8 bbl are to be found for every barrel produced in 1960, the discovery rate will have to be stepped up to 4.25 billion bbl per year within ten years. Such large discovery rates never have been maintained in the past, so the job ahead is much greater than ever before.

No one can know in any exact or even approximate sense what the discoveries of a year or even a month in advance may be; nor whether there may be no more, one more, or a dozen deposits such as East Texas or Scurry waiting to be found. Present trends indicate that the discovery of another big oil reserve would certainly be a welcome event. ★ ★ ★

Effect of Drilling Fluids on Production

Reported by Herman Dykstra
Pacific Technology Group

The second lecture of the present series on research, sponsored by the Pacific Technology Group, was given by C. C. Wright of Oilwell Research, Inc., at the General Petroleum Auditorium in Los Angeles.

Wright described a number of tests that were used to evaluate drilling fluids and showing how effective oil permeability was affected. Natural cores were used for most of the tests and usually five cores were selected to cover a permeability range. Two types of tests were made: (1) cores were mudded off at 100 psi differential across the core, and (2) filtrate was passed through the core. Tests were conducted with clay winter muds, oil base muds, and emulsion muds.

Cores were first saturated with the proper formation water and were then placed in a capillary pressure cell at 35 to 40 psi to obtain minimum water saturation. After the cores were at equilibrium the oil permeability was measured and was used as a reference permeability.

For the first type of test where the cores were mudded off only 0.2 to 0.3 cc of filtrate passed into the core and the kerosene permeability measured immediately after the cores were mudded off. For the second type of test two to three pore volumes of filtrate were passed through the cores and the cores were allowed to stand for 24 hours before the kerosene permeability was measured.

The return permeability was measured at two and sometimes three different pressure drops across the core; 1.5 and 15 psi if only two pressures were used, and 3 psi in addition to the above if three pressures were used. For all the tests the return permeability increased with increasing pressure drop and at 15 psi differential, all the return permeabilities were greater than 49 per cent of the original kerosene permeability and only three were less than 75 per cent. For one set of cores, however, the return permeability was greater than 100 per cent of the original oil permeability. This set of cores had been saturated in the capillary pressure cell at only 15 psi so that the minimum water saturation was not obtained and the chemical nature of the filtrate that passed through the core was such that the core became dehydrated. Consequently, when the return permeability was measured at 15 psi pressure drop, more water was driven out of the core than was removed in the capillary pressure cell. The higher oil saturation at the conclusion of the test then gave a return permeability greater than 100 per cent of the original kerosene permeability.

Another set of tests made by another laboratory was described by Wright. These tests were made to determine the effect of using a commercial bridging agent in a clay-water mud with 20 per cent oil but no emulsifying agent. Alundum cores were completely saturated with 50-50 mixture of xylene and white oil and their oil permeabilities were

Continued on Page 7, Section 2

Predicting Reservoir Performance

Reported by John Clayton Jacobs, Jr.
North Texas Study Group

The current discussions of the Dallas study group of the North Texas Section deal with the application of fluid flow equations and material balances to predict reservoir performance. Two of the four discussions of these subjects were held last month, led by A. B. Dyes of The Atlantic Refining Co., with active participation by representatives of other companies. The more pertinent observations of the discussions concerned with flow of fluids are summarized as follows:

1. Flow rates encountered in oil reservoirs are generally small enough to be described by viscous flow and Darcy's law. This condition is also present in gas reservoirs except in the vicinity of the well bore where rates are perhaps large enough to cause turbulent flow. The departure from Darcy's law in this area may account for the disagreement between the procedures developed by the U. S. Bureau of Mines for predicting gas flow rates and that which would be based wholly upon Darcy's law.

2. Little difference exists between the two pressure distributions that occur under steady state flow in which the flow rate at the external boundary is considered either zero or equal to the flow rate at the internal radius (well bore). Consequently, little difference arises in well productivity studies. However, in the application of pressure build-up measurement, to the determination of equalized reservoir pressure, the type flow rate which is considered at the outer radius can lead to significant differences in calculated build-up pressure.

3. The time required to establish steady state conditions is a function of the permeability, and in reservoirs of low permeability (1 md), this amounts to several weeks. For lower values of permeability the time required to establish steady state extends into months. Consequently, a prolonged decline in productivity index is to be expected in reservoirs of this type.

4. An analysis of pressure build-up data can define the reservoir permeability away from the well bore and can be used to calculate the final build-up pressure. In conjunction with productivity indices tests, these data can be used to indicate improvement or damage in the permeability in the vicinity of the well bore in evaluating mud damage, gas blockage, potentialities and results of acidization and hydrofrac treatments.

5. Use of relative permeability data with Darcy's law to describe the flow of fluids through porous media is valid if these data have been obtained for the same direction of desaturation as occurs in the process to which these data are to apply.

6. In general, the gas/oil ratios of oil reservoirs increases at lower gas saturation than would be predicted from relative permeability data obtained on individual core plugs. It is thought that this discrepancy lies in the adequacy of present sampling and intepretative procedures.

7. Application of relative permeability data leads to reliable estimates of the productivity to be expected from any well at a given state of depletion.

The discussion of the application of relative permeability data to the prediction of ultimate recovery by solution gas drive, water flood and gas injection, was to be continued at the next bi-weekly meeting. ★ ★ ★

Research Labs Open to Public Use

The facilities of Sinclair Research Laboratories, a multi-million dollar petroleum research plant at Harvey, Ill., are being thrown open to "any American with an idea for a new or better petroleum product or application," P. C. Spencer, president, has announced. The entire operation of "The Sinclair Plan" centers at the newly-formed Sinclair Research Laboratories, a wholly-owned subsidiary of Sinclair Oil Corp.

Spencer pointed out that while Americans have always been an inventive people, in our early days an amateur mechanic or scientist could invent and prove a device in his attic, basement or garage.

"Henry Ford did it that way. So did Edison, the Wright brothers and hundreds of others," Spencer said.

"Today, however, the man with an idea often needs years of time, the help of an army of specialists, and thousands, even millions of dollars' worth of equipment to prove out his invention. This plan provides all the necessary technical facilities and skilled personnel to any American with an accepted idea, to bring that idea from the roughest scratch-pad stage through to final pilot-plant testing.

"Here at Sinclair Research Laboratories extensive facilities will be made available to the public for the study, development and proving out of ideas."

According to the plan, the laboratories will test the most promising ideas selected by the laboratories' directors. In return for its investment of money, time, facilities and personnel, Sinclair receives the privilege of using the invention free of royalties.

"This in no way impairs the inventor's opportunity to sell his idea in all other quarters, or to make any kind of arrangement he wishes outside of his agreement with Sinclair," Spencer said. Every idea submitted, it was emphasized, must first be protected by a patent application or a patent.

Comprising nine new buildings situated on 38 acres, the laboratories can process in close succession several major ideas through required specific phases of research.

Recently elected officers of the laboratories are E. W. Isom, chairman; Spencer, president; W. M. Flowers, executive vice-president, and E. C. Herthel, vice-president. Directors include Isom, Spencer, Flowers, Herthel and W. R. Argyle, E. L. Hughes, T. B. Kimball, W. H. Morris and H. L. Phillips. ★ ★ ★

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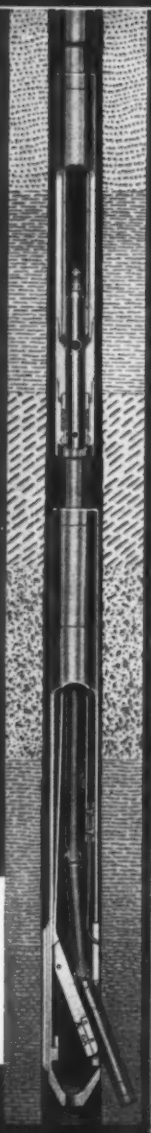

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DISCUSSION OF THIS AND ALL FOLLOWING TECHNICAL PAPERS IS INVITED
Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 408 Trinity Universal Bldg., Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 31, 1951. Any discussion offered thereafter should be in the form of a new paper.

EFFECT OF FREE GAS SATURATION ON OIL RECOVERY BY WATER FLOODING

C. R. HOLMGREN AND **R. A. MORSE,** JUNIOR MEMBERS AIME, STANOLIND OIL AND GAS CO., TULSA, OKLA.

ABSTRACT

The production of oil by water flooding can be substantially increased by the maintenance of free gas saturation in the reservoir during the flooding operation. This effect is accomplished by the alteration of oil relative permeability characteristics and the occupation by gas of pore space that would otherwise be filled with residual oil. The amount of reduction in residual oil can be calculated from appropriate water-oil relative permeability characteristics.

This paper presents experimental data in support of the foregoing conclusions and an example of the calculations. The microscopic pore saturation concepts of the mechanism are discussed. A method of practical application to field floods is presented together with discussion of certain limitations.

INTRODUCTION

The presence of free gas has been reported by a number of investigators to significantly affect the oil recovery which can be obtained from sandstone flow systems by water flooding.[1,2,3,4,5] The effect of gas, noted in every instance, has been to cause lower residual oil saturations than could be obtained by water flooding the same systems in the absence of free gas. The degree of improvement in recovery has been observed to vary widely, depending on the systems used and the conditions of the tests. The increased oil recovery obtained because of the presence of gas during a water flood has been variously attributed to changes in physical characteristics of the oil, selective plugging action of the gas, inclusion of oil mist in the free gas phase, and the additional sweeping or driving action of the free gas.

All but the first of these suggestions imply changes in the displacement mechanism. The change in viscosity and interfacial tension of the oil phase, within the pressure range used for all the experimental work, is certainly not sufficient to account for the differences in residual oil saturation noted unless there is a drastic change in the displacement process.

One other effect which logically seems capable of causing differences in residual oil saturation of the magnitude noted in the experimental work is that of simple replacement. In a water-wet system containing oil, water, and gas, it is to be expected that the gas will exist inside the oil. This is the position of minimum free surface energy, since the gas-oil interfacial tension will be less than the gas-water interfacial tension. There is no apparent reason to expect that the existence of free gas within the oil phase should alter the saturation at which the non-wetting phase (now oil and gas) should become discontinuous and hence trapped so as to be unrecoverable by direct displacement by water. If this is the situation, then trapping of a certain percentage of gas saturation during water flood should result, at infinite water-oil ratio, in a like reduction of oil saturation below that attainable by flooding in the absence of free gas. It is visualized that the gas will exist as bubbles inside the discontinuous residual oil as illustrated in Fig. 1, with the size of the oil bubbles being substantially unchanged due to the presence of the gas. As a practical matter, it can be anticipated that the presence of a free gas saturation inside the oil phase will reduce the relative permeability to oil which will exist at any particular water saturation. This reduction will be caused by two factors — the addition of the gas-oil interface, and the reduction of area available for oil flow in the pores containing gas. This reduction in oil permeability at any particular water saturation will result in water breakthrough at a lower water satu-

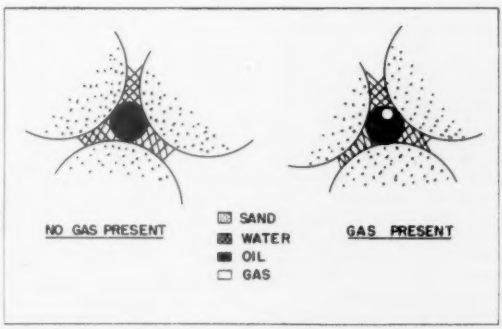

FIG. 1 — CONCEPT OF OIL AND GAS LOCATIONS IN PORE SPACE AT RESIDUAL OIL SATURATION.

[1]References given at end of paper.
Manuscript received in the office of the Petroleum Branch Sept. 15, 1950. Paper presented at the Petroleum Branch Fall Meeting in New Orleans, La., Oct. 4-6, 1950.

ration and higher water-oil ratios for a given water saturation following breakthrough, than would be obtained if gas were not present.

It has been impossible to quantitatively evaluate, from the available experimental work, the effects of free gas on water flooding because of one complicating factor common to all experimental work; that of unmeasured variations of gas saturation at the water flood front. Water flooding of a linear system, partially saturated with oil and gas, results in the formation of an increasingly wide oil bank ahead of the injected water. The moving oil bank will displace gas ahead of it, reducing the gas saturation to some residual value immediately behind the front of the oil bank. The movement of the oil bank will cause the pressure on the residual gas to be increased above the value at which it was trapped. The amount that the pressure on the gas will be increased, before the water flooding front reaches it, will depend on the width of the oil bank, the oil permeability, and the flow rate. As the pressure increases, the gas will be reduced in volume due to compression and solution. If the pressure is increased enough between the time the gas is trapped and the arrival of the water flood front, all of the gas may be put into solution in the oil, causing the system to revert to one of two liquid phases. The gas saturation existing at the water flood front may have any value between zero and the maximum residual gas trapped at the front of the advancing oil bank. If improved water flooding oil recovery is dependent on the existence of a free gas phase, the mere existence of an initial gas saturation before flooding begins would not necessarily insure that lower oil saturations could be obtained than could be obtained by flooding a completely liquid saturated system.

One way to avoid the complication of varying gas saturation during the water flooding process would be to conduct the flood at a pressure differential which is very small compared to the absolute pressure of the system. In this way the residual gas saturation at the water flood front can be kept substantially the same as that in the entire oil bank. The amount of this residual gas saturation should then be merely a function of the relative permeability characteristics of the sand and the saturation conditions prior to the flood.[5] Experimental work reported in this paper was conducted under these conditions with the specific objective of isolating the effects of a static free gas phase on water flooding recovery as differentiated from any alteration in the displacement mechanism occasioned by the presence of mobile gas.

APPARATUS AND MATERIALS

The core in this investigation was five in. in diameter and five ft long. It was quarried from an outcrop near Sand Springs, Okla., and ground to a cylindrical shape. This sandstone, which is known as the Nellie Bly, is well consolidated and has an average porosity of about 27.4 per cent. The average specific permeability to water of this core was 612 md.

Piezometer rings made of brass cups and tubing were placed on the core at intervals. End plates, thermocouples, and an additional conductivity ring were attached and the assembly sealed with a viscous rubber compound which set up into a hard impervious coating. This core assembly was mounted in a heavy steel housing. Outlets from the piezometer rings were electrically insulated through the housing so that piezometer rings served as conductivity electrodes as well as pressure measurement taps.

Fig. 2 is a schematic diagram of the apparatus, which consists of the core assembly, liquid-gas separators, recording flowmeters, filters, and sight gauges. Means were provided to record differential pressures across any desired interval or intervals along the core. Electrical conductivity, from which brine saturation could be obtained, could also be measured across any desired interval. The entire apparaus was designed to operate at pressures up to 1,000 psi and temperatures to 150°F.

The oil used in these experiments was a close-cut naphtha having a density of .767 gm/cc and a viscosity of 0.990 cp at 80°F. In the experiments the oil was saturated with methane at pressures varying from 388 to 517 psi, and under these conditions, the approximate viscosity range was from .75 to .85 cp.

The water was a prepared brine having approximately 33,000 ppm *NaCl*. Sodium nitrate was added to inhibit corrosion and the *pH* value was adjusted to about 7.7. The gas used was commercial grade (96 per cent) methane.

PROCEDURE

The core was initially saturated 100 per cent with brine, the reference electrical conductivity was obtained, and the brine saturation reduced to a value in the range of 26.4 to 30 per cent by flooding with oil. The oil circulated to reduce the water saturation was saturated with methane. When the water saturation had been reduced to a sufficiently low value, with the remaining pore volume being saturated with live oil, the core was further prepared for the flood tests by one of the three following methods:

1. A gas drive was conducted at constant pressure until the gas saturation was increased to a sufficiently high value that subsequent oil flooding would obtain the desired residual gas saturation. Fig. 3 is a plot of the relationship between the maximum gas saturation obtained by the gas drive versus the residual gas saturation retained in the core following oil flooding. Once the desired maximum gas saturation was obtained, gas-saturated oil was injected into the core under low pressure differentials in order to displace excess free gas. Circulation of the oil was maintained until no further gas was produced from the core. Once the residual gas saturation became stabilized, the core was ready for water flooding.[6]

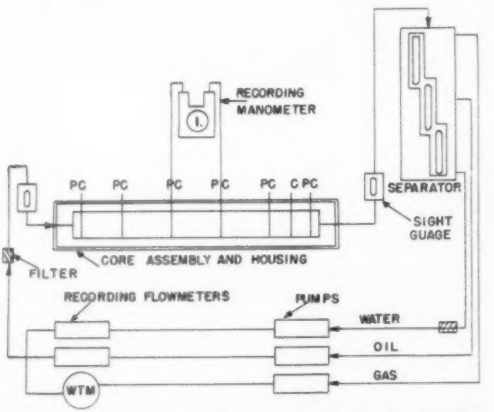

FIG. 2 — SCHEMATIC SKETCH OF EXPERIMENTAL EQUIPMENT.

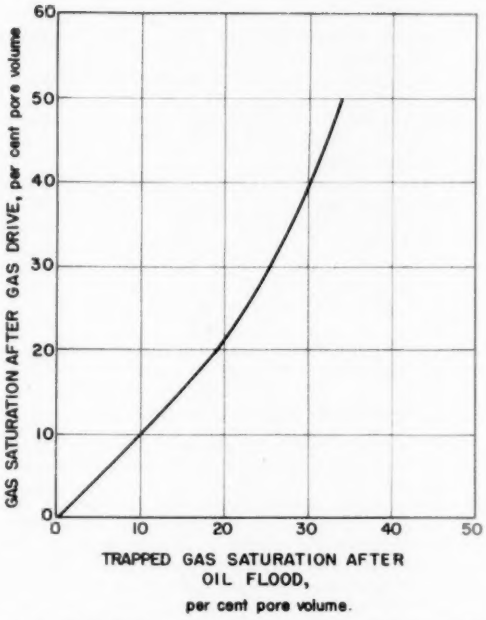

FIG. 3 — RELATIONSHIP BETWEEN MAXIMUM GAS SATURATION OBTAINED BY GAS DRIVE AND TRAPPED GAS SATURATION AFTER OIL FLOOD.

2. A procedure identical with (1) above was used to establish a certain gas saturation which was followed by pressure reduction in the system to allow expansion of the trapped gas saturation. The amount of pressure reduction was small enough that no free gas was produced due to expansion of the trapped gas. Oil was circulated at the lower pressure to remove any super-saturated liquid and to insure that the gas saturation had not been increased to the point where it would be produced upon water flooding.
3. Previous to one flood the system was subjected to an internal gas drive down to a pressure of 300 psia from an original saturation pressure of 500 psia.

The fluids were contained in a closed system after the establishment of 100 per cent liquid saturation so that any variation in either oil or water content was reflected in a change in level in the production separator. This separator was calibrated so that production could be measured to an accuracy of 0.1 per cent of the pore volume. The average gas saturation prior to water flooding was determined by means of a material balance in the liquid system. Once the core had been prepared as outlined above, the water flood was conducted by injection of water at rates low enough that the maximum pressure gradient in the flow system was less than 2.7 psi/ft. Flooding was continued until the water-oil ratio was above 100.

It was originally planned to obtain free gas saturations below the equilibrium value, which was expected to be of the order of magnitude of seven to eight per cent, by a slight reduction of pressure on the system saturated with water and gas-saturated oil. It was believed, on the basis of experimental work reported by other investigators, that such a process would result in the most uniform possible distribution of free gas. However, initial attempts to obtain gas saturation by this means resulted in failure. Equilibrium vaporization data indicated that only slight pressure reductions would be necessary to form gas saturation of less than ten per cent. Such pressure reductions on the system resulted in almost no oil production and hence no free gas formation. It was found that the pressure could be reduced in excess of 50 lb below the equilibrium bubble point prior to any significant production. Reduction of the pressure to the point where oil production started resulted in gas saturations which were not reproducible from one run to the next. Supersaturation of the oil below the bubble point pressure, as indicated here, is not a peculiar characteristic of this rock-fluid system. It has been observed in every system where investigation of the phenomenon has been made, and is presently a subject of investigation in this laboratory. The technique was then revised to obtain a stable free gas saturation by means of gas drive followed by oil flooding at constant pressure, as described above.

After the water flood, the final gas saturation was determined as a check on original material balance calculations. This was done by circulating dead oil, furnished from a container external to the regular flow system through the core and into the separator. The difference between the amount of liquid produced into the separator and the amount of dead oil injected into the system, at the time when the core reached 100 per cent liquid saturation, represented the amount of gas in the system at the start of the dead oil flood, since the dead oil absorbed and replaced the free gas in the pore space. At the finish of a flood, the dead oil was flushed from the core by gas-saturated oil, and the water saturation reduced by further oil circulation, making the core ready for another experimental cycle.

RESULTS

Tables I and II summarize the pertinent data on saturation conditions prior to water flooding, at water breakthrough, water-oil ratio of approximately 100, and final conditions. Portion of this data are shown graphically in Fig. 4.

The flood in Run 1 shown in Table I was conducted with the core initially 100 per cent saturated with water and live oil to establish a standard of comparison for the later tests in which free gas was to be present prior to flooding. The data from this run check very closely with the performance of a number of other floods in which the oil was not saturated with gas.

Table I

Summary of Data for Floods in Which Static Gas Saturation Was Obtained by Oil Flood Only

Run Number	1	2	3	4	5	6
Original Water Sat., % Pore Vol	30.0	28.3	28.4	27.7	27.2	27.0
Original Oil Sat., % Pore Vol	70.0	63.0	62.7	70.0	47.5	56.0
Original Gas Sat., % Pore Vol	0	8.7	8.9	2.3	25.3	17.0
Average Outlet Pressure, psia	517	465	465	388	505	490
Oil Prod. to Breakthrough, % Pore Vol.	33.0	31.2	33.0	36.8	26.0	30.2
Total Oil Produced, % Pore Vol	36.0	33.1	36.0	37.9	30.7	32.7
Water Sat. at Breakthr ugh, % Pore Vol	63.0	59.5	61.4	64.5	53.2	57.2
Residual Oil Sat. at 100-1 water-oil ratio), % Pore Vol	34.0	29.9	26.7	32.1	18.8	23.5
Water Saturation, % Pore Vol. (at 100-1 water-oil ratio)	66.0	62.1	64.1	66.4	56.7	59.1
Final Water Saturation, % Pore Vol	66.0	62.1	64.1	66.4	58.7	60.1
Final Gas Sat., % Pore Vol. (by difference)	0	8.0	9.2	1.5	24.5	16.6
Final Gas Sat., % Pore Vol. (by dead oil replacement)			9.2	2.1	24.6	17.2
Reduction in Resid. Oil from Run 1 % Pore Volume		4.1	7.3	1.9	17.2	10.7
Average Flow Rate, cc/min	1.62	1.40	1.47	1.25	1.50	1.52
Total Water Throughput, Pore Vols	613	592	626	669	4.381	1.240

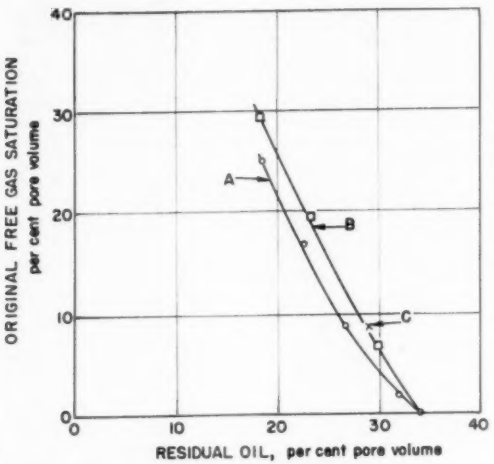

FIG. 4 — RELATION BETWEEN FREE GAS SATURATION AND RESIDUAL OIL SATURATION AT 100:1 WATER-OIL RATIO. CURVE A — GAS TRAPPED BY OIL FLOOD ONLY; CURVE B—GAS TRAPPED BY OIL FLOOD AND EXPANDED BY PRESSURE REDUCTION; POINT C — GAS ESTABLISHED BY INTERNAL DRIVE.

The initial gas saturation for the series of tests summarized in Table I was established by gas driving followed by oil flooding with no change in pressure. It is believed that this method yields the most uniformly distributed gas saturation possible. It will be noted from these tests that at low gas saturations, the reduction in oil saturation below that of the reference run is only slightly less than the free gas saturation. Each succeeding increment of initial free gas saturation results in a smaller decrease in oil saturation, at reasonable water-oil ratios, until, at the highest gas saturation used (25.3 per cent), the total reduction was 15.2 per cent of the pore volume. This trend has been anticipated and is caused by the decreasing relative permeability to oil occasioned by increasing gas saturation.

An attempt was made, in Run 5, to check the postulation that the total saturation of the non-wetting phase or phases (oil or oil plus gas) ultimately attainable at infinite water-oil ratios should be independent of the amount of free gas. This water flood was conducted for a period of ten days with a resultant oil production increase of two per cent above that at a water-oil ratio of 100. The rate of oil production was so low that several weeks of additional flooding time would have been necessary to reach the same water saturation as that obtained on the reference flood. Because of the excessively long time involved, the flood was discontinued without establishing the relationship between gas saturation and residual non-wetting phase saturation at zero permeability to oil. This point has little significance from the standpoint of application to field flooding, but should be established to clarify present concepts on the microscopic aspect of fluid displacement.

It was recognized that the relationship between residual oil and original gas saturation was not unique but would depend on the distribution of the saturation.[6] For example, the effect on oil recovery of an average gas saturation of 20 per cent resulting from 33 per cent saturation in only 60 per cent of the pore openings would be expected to differ from that of the same average gas saturation distributed uniformly in every pore. It is tentatively believed that the extremes possible in gas saturation distribution are those obtained by

(1) flooding at constant pressure from an initial maximum gas saturation, or

(2) displacement of liquid by increasing gas saturation.

Accordingly, the initial gas saturations for the runs summarized in Table II were established by trapping a certain amount of residual gas by oil flooding and expanding that gas by pressure reduction.

The data from this series of tests, shown as Curve *B* in Fig. 4, clearly demonstrate that a given gas saturation established by the gas expansion technique resulted in somewhat less increased oil recovery than the same saturation established by the flooding at constant pressure technique. However, by either method, the residual oil saturation could be very substantially reduced from the case in which no free gas was present.

In one test, Run 10, the initial gas saturation was established by internal gas drive (Point *C*, Fig. 4).

INTERPRETATION OF RESULTS

If the effect of static free gas saturation during water flooding is merely replacement of residual oil combined with reduction of oil permeability, it should be possible to calculate these effects by means of the frontal drive method of Buckley and Leverett.[7] The only complication is that the necessary water-oil relative permeability relationship must be measured with the proper static gas saturation. In order to determine the applicability of such a procedure, relative permeabilities were measured at 25 per cent gas saturation in the system upon which the above discussed floods were conducted. The preliminary treatment of the core to establish the gas saturation was the same as that used for the first series of tests — gas drive followed by oil flood at constant pressure. After the gas saturation was established, oil and water were injected simultaneously into the core at fixed ratios until saturation equilibrium was established at each flowing ratio. Equilibrium was determined by stabilization of electrical conductivity and pressure differentials. The saturations and pressure drops for the relative permeability calculations were measured in the center foot of the five-ft core to eliminate disturbing end effects. Flow rates were low enough so that the over-all pressure differentials were less than ten psi. The relative permeability data at 25 per cent gas saturation are shown in Fig. 5 together with the relative permeability characteristics on the

Table II

Summary of Data for Floods in Which Static Gas Saturation Was Obtained by Oil Flood Followed by Pressure Reduction or by Internal Gas Drive

Run Number	7	8	9	10
Original Water Saturation, % Pore Vol	26.8	29.0	27.2	26.4
Original Oil Saturation, % Pore Vol	43.5	51.3	65.8	64.9
Original Gas Saturation, % Pore Vol. (Before Expansion)	26.1	14.4	5.3	0.
Original Gas Saturation, % Pore Vol. (After Expansion)	29.7	19.7	7.0	8.7
Final Water Saturation, % Pore Volume	54.5	60.2	63.0	64.1
Final Oil Saturation, % Pore Volume	16.7	22.4	29.8	28.8
Residual Oil, % Pore Volume (at 100 to 1 water-oil ratio)	18.2	23.1	29.8	29.0
Residual Oil, % Pore Volume* (at 100 to 1 water-oil ratio) (Before Expansion)	18.0	23.3	29.0	34.0
Final Gas Saturation, % Pore Volume (by dead oil replacement)	29.2	17.7	7.4	8.9

*This is the residual oil that previous data indicate would have been attained had the system been flooded under conditions before gas expansion.

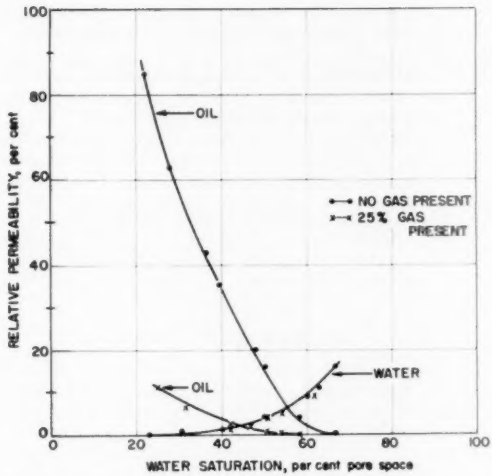

FIG. 5 — RELATIVE PERMEABILITY TO OIL AND WATER FOR TWO SYSTEMS IN NELLIE BLY SANDSTONE.

same system containing only oil and water. At any particular water saturation, oil relative permeability is drastically reduced when free gas is present, but water permeability is identical for the two conditions. A very important factor is that permeability to oil persists to much lower oil saturations with free gas present.

Fig. 6 is a plot of the construction necessary to compute the average water saturation at water breakthrough by the Buckley and Leverett frontal drive method with simplifications added by Pirson.[5] The calculations in this figure are for the reference run when no gas saturation was in the system. The computed average water saturation at water breakthrough is 65 per cent compared to the experimental value of 63.0 per cent. This difference can be attributed largely to dispersion of the flood front caused by capillary forces neglected in the simplified calculation. Fig. 7 shows the results of the same type computation for the system containing 25 per cent free gas saturation. The calculated average water saturation at breakthrough is 54.5 per cent; the experimentally obtained value, 53.2 per cent.

If the replacement of residual oil by gas had been in a 1:1 ratio, the reduction in residual oil would be equal to the gas saturation, or 25 per cent. Since a 1:1 ratio is not achieved, the reduction in residual oil at water breakthrough should equal the gas saturation less the difference in water saturations at breakthrough. From the computation of Figs. 5 and 6, this would be .25 – (.65 – .545) = .145 or 14.5 per cent. The difference obtained experimentally was 15.5 per cent. The close check between the experimental results and those calculated from appropriate relative permeability data leads to the conclusions that:

(1) The effects of free gas in water flooding are the alteration of oil relative permeability characteristics and the occupation of space which would otherwise be filled with residual oil.

(2) The reduction in residual oil which can be expected by the maintenance of free gas saturation during water flooding in a particular reservoir rock can be calculated from appropriate water-oil relative permeability characteristics.

The degree of improvement in oil recovery by water flooding which can be accomplished by maintenance of free gas saturation during the flood can be expected to vary widely between different reservoir materials. It would be gross speculation to attempt estimation of the benefits to be derived from a particular reservoir without measurements on cores from that reservoir.

PRACTICAL APPLICATION

It is obvious from the foregoing that maintenance of a maximum free gas saturation during water flooding can very substantially reduce residual oil saturation and hence increase oil recovery, providing it is feasible for application to a particular reservoir. Improved recovery of the magnitude indicated by the experimental work reported herein, could result in doubling the water flooding recovery from some semi-depleted fields. Of comparable importance in the water flooding of depleted reservoirs are the smaller volume of water required for fill-up, the earlier start of water flood production, and a more uniform oil producing rate.

One readily apparent means of accomplishing the maintenance of such a gas saturation is by gas injection to build up the reservoir pressure to such a level that the pressure differential across the oil bank will be a small fraction of the absolute pressure and thereby reduce compression of the gas present. A means of eliminating a large part of the loss of free gas due to solution in the oil is the injection of a gas of low solubility, such as nitrogen.

A very significant feature in the application of free gas saturation maintenance during water flooding is the reduction

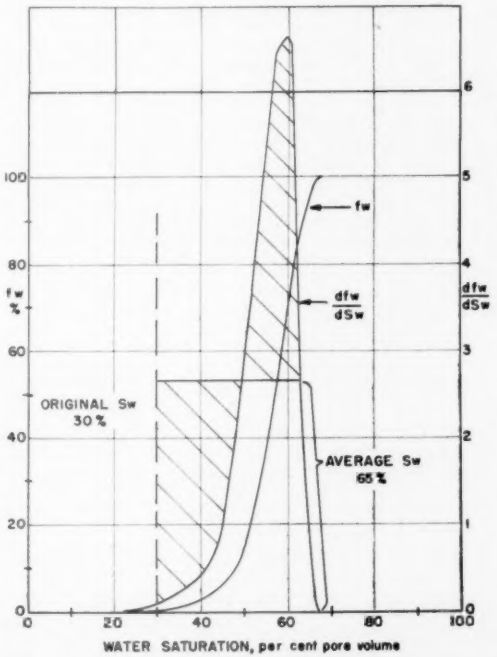

FIG. 6 — COMPUTATION BY FRONTAL DRIVE METHOD OF BREAKTHROUGH WATER SATURATION WITH NO GAS PRESENT.

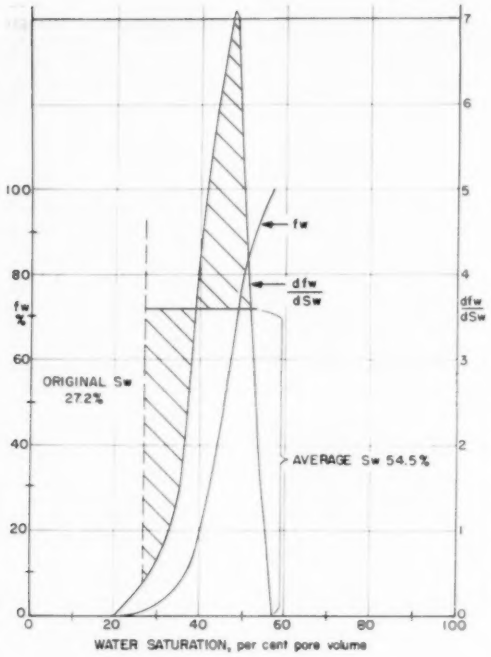

FIG. 7 — COMPUTATION BY FRONTAL DRIVE METHOD OF BREAK-THROUGH WATER SATURATION WITH 25 PER CENT GAS SATURATION PRESENT.

in capacity of producing wells. High gas saturation in the reservoir can reduce oil permeability to the order of magnitude of 1/10 the specific permeability as indicated by the relative permeability curves of Fig. 5. This permeability reduction will cause a reduction of the same magnitude in the productivity indices of the wells. Whether operations can be conducted at such reduced producing capacities may be of controlling importance in determining application to some fields.

Whether it will be economically feasible to reduce pressure in primary water drive fields to cause internal evolution of free gas ahead of the water flood front will be determined by a number of factors, such as

(1) The shrinkage of oil, resulting from pressure reduction necessary to obtain the gas saturation, compared to the expected decrease in ultimate oil saturation.

(2) Marked decreases in productivity indices of producing wells and hence an increased tendency for water coning.

(3) Variation in oil properties with structure. Some high relief reservoirs have much lower bubble point oil at the water-oil contact than further up structure. Under such conditions it would be almost impossible to obtain free gas at the water-oil contact without depletion by internal gas drive of the upstructure part of the field.

ACKNOWLEDGMENT

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VAPORIZATION CHARACTERISTICS OF CARBON DIOXIDE IN A NATURAL GAS-CRUDE OIL SYSTEM

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ABSTRACT

The vaporization characteristics of carbon dioxide in a League City natural gas - Billings crude oil system were studied at three temperatures, 38°, 120°, and 202°F and for pressures ranging from 600 to 8,500 psi. Variation of carbon dioxide concentration up to 12 mole per cent in the composite showed no effect on the equilibrium vaporization ratios (K values) of the hydrocarbon constituents or on the K value of carbon dioxide itself. It was shown that carbon dioxide is more soluble in crudes than in distillates which is contrary to the behavior of methane.

A working chart of carbon dioxide K values is presented.

INTRODUCTION

The study of the equilibrium vaporization ratios of mixtures of paraffin hydrocarbons has been rather thorough.[2,4,7,8,9] In the past few years considerable attention has been paid to the vaporization characteristics of the so-called noncondensable gases such as nitrogen, carbon dioxide, and hydrogen sulfide in mixtures of hydrocarbons, since they usually occur to some extent in most crude oils and natural gases.[1,3,4,5] Knowledge of this behavior is useful to both the production and refining phases of the petroleum industry.

This paper reports the equilibrium vaporization ratios (K's) of carbon dioxide in a mixture of League City natural gas and Billings crude oil, and compares them to those obtained in a natural gas-distillate system.[3] The equilibrium vaporization ratios for the hydrocarbon components in this system had previously been studied by Roland.[7] In addition to the determination of the K values for carbon dioxide, the K values for methane and ethane were also determined in order to observe what effect, if any, the presence of carbon dioxide had on these K values. The concentration of carbon dioxide was also varied in order to observe the effect of this variable on the carbon dioxide K values.

EXPERIMENTAL PROCEDURE

The apparatus used in this study consisted of a stainless steel equilibrium cell of about 2 liters capacity. The cell was mounted on trunions permitting rocking in a thermostatically controlled oil bath. Two high pressure valves fitted with steel tubing were mounted on the top of the cell, one was used for sampling the equilibrium gas phase and the other for sampling the equilibrium liquid phase by means of an induction tube within the cell. Stainless steel tubing from the bottom of the cell led to a mercury reservoir and manifold which was connected to a free-piston type pressure gauge manufactured by the American Instrument Co. and to a volumetric pump. The temperature of the oil bath was measured by means of a calibrated mercury-in-glass thermometer. The recorded temperatures are believed to be accurate to ±0.5°F. The pressures are correct to ±2 psi.

The crude oil used in this study was stock tank oil obtained from the Wilcox formation in the Billings Field, Noble County, Okla. The natural gas was obtained from the League City Field, Galveston County, Tex. The oil was treated with anhydrous calcium sulfate in order to remove the last traces of water. To insure a supply of constant composition gas at room temperature the cylinders of League City gas were cooled to about 30°F, inverted, and the condensed liquid was allowed to drain from the cylinders. The analysis of the gas and crude are tabulated in Table I. The carbon dioxide came from Pure Carbonic, Inc., and was stated to have a purity of 99.5 per cent or better.

The procedure used to obtain samples of the equilibrium liquid and vapor was similar to that employed by others making use of the rocking type equilibrium cell.[6,7,9]

The equilibrium cell was evacuated and calculated quantities of carbon dioxide, natural gas, and crude oil were charged to the cell to the desired pressure. In charging the equilibrium cell an attempt was made to maintain the ratio of the natural gas to crude oil as close as possible to that employed by Roland.[7] After the cell was charged, samples of

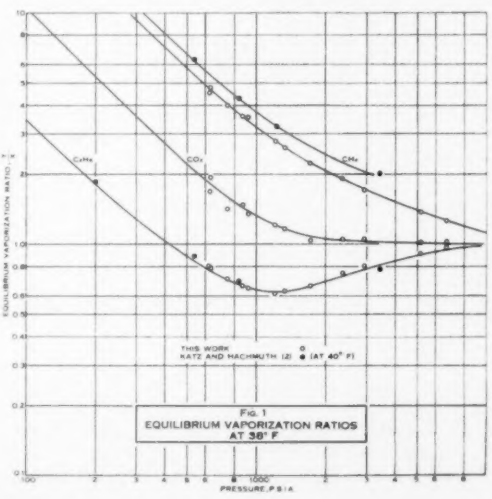


FIG. 1
EQUILIBRIUM VAPORIZATION RATIOS AT 38° F

[1]References given at end of paper.
Manuscript received in the office of the Petroleum Branch Aug. 9, 1950.

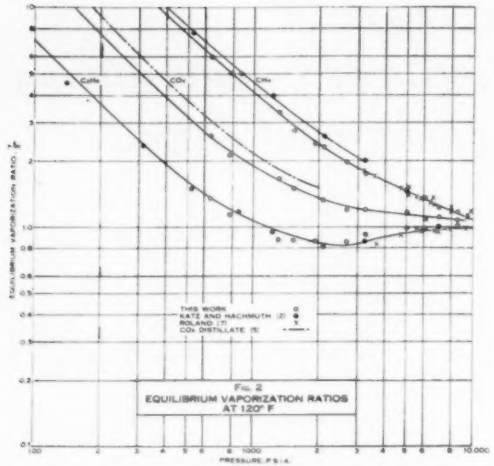


Fig. 2
EQUILIBRIUM VAPORIZATION RATIOS AT 120° F

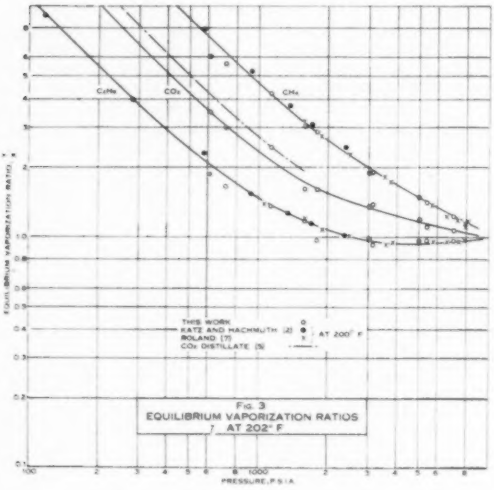


Fig. 3
EQUILIBRIUM VAPORIZATION RATIOS AT 202° F

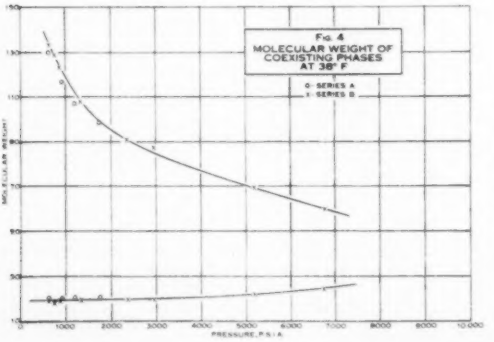


Fig. 4
MOLECULAR WEIGHT OF COEXISTING PHASES AT 38° F

equilibrium liquid and vapor were removed until one of the phases was depleted. By sampling the proper quantities of vapor and liquid the over-all composition of the fluid in the cell was maintained relatively constant.

After the pressure in the cell was adjusted to the desired value by adding or removing mercury in the cell, the cell was rocked to insure equilibrium between the phases. The samples of vapor and liquid were then obtained by constant pressure displacement with mercury. The phase being sampled was flashed into a trap and the gas leaving the trap was caught in previously evacuated glass bulbs of known capacity. In using this procedure it was assumed that all of the methane, carbon dioxide, and ethane went into the gas phase and none remained behind in the liquid phase remaining in the trap. The trap liquid was weighed and its molecular weight and gravity determined. The total moles of gas trapped in the glass bulb were calculated. The carbon dioxide content of the gas was determined by means of the infrared spectrometer and the methane and ethane content was determined by means of the mass spectrometer.

Two series of samples were taken, series *A* composite charge contained about 11.50 mole per cent carbon dioxide and series *B* about 6.25 per cent carbon dioxide.

EXPERIMENTAL RESULTS

Table II shows a summary of the experimental results obtained in this investigation. A total of 34 pairs of equilibrium vapor and liquid samples were taken. The *K* values were investigated at three temperatures, 38°, 120°, and 202°F. Pressures ranged from 600 to 8,500 psi.

The composite analyses shown on Table II were determined by means of a material balance and the analyses of the phases sampled.

The *K* values obtained are plotted in Figs. 1, 2, and 3, as the logarithm of *K* versus the logarithm of pressure for each temperature investigated.

In making the composite calculations, the molecular weights of the coexisting equilibrium vapor and liquid phases were also determined and are shown plotted on Figs. 4, 5, and 6 for the three temperatures investigated.

Table III summarizes the data on the molecular weights and specific gravities of the trap liquids. These data are plotted in Fig. 7.

DISCUSSION OF RESULTS

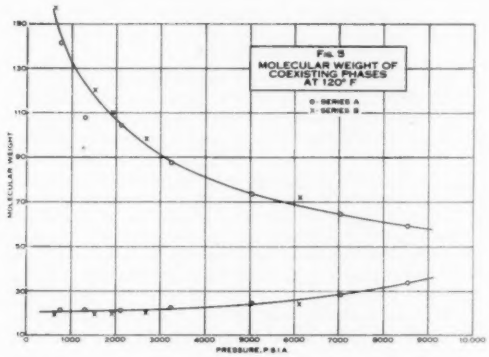
In addition to the data obtained in this study, the data of Roland[7] and Katz and Hackmuth[2] are also plotted on Figs. 1, 2, and 3. The data of Roland[7] for the Billings crude oil - League City gas system for methane and ethane agree very well with those determined in this study indicating that the

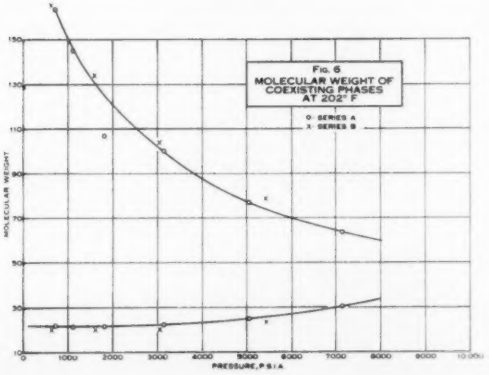
Table I — Analysis of Oil and Gas

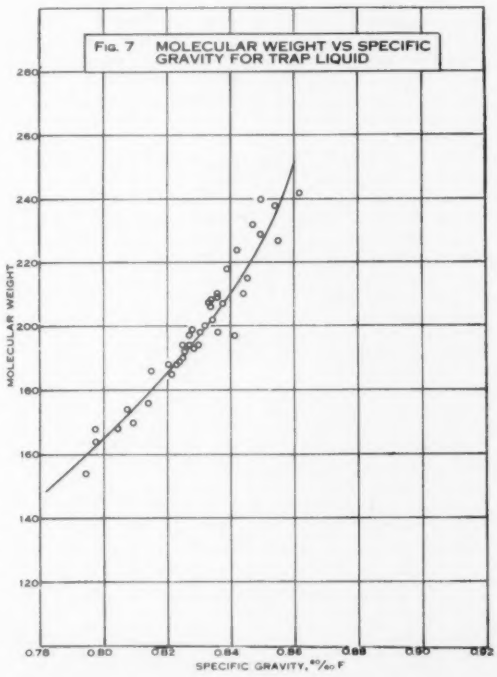
	Billings Crude	League City Gas
Carbon Dioxide		1.20
Methane		90.89
Ethane	1.41	4.40
Propane	1.44	1.91
Butanes	2.19	0.93
Pentanes	3.68	0.34
Hexanes	5.48	0.15
Heptanes Plus	85.80	0.18
Sp Gr	0.8353 60/60 F	
Mole Wt	205	

Table II — Summary of Experimental Results

Charge No.	Equilibrium		Composite				Vapor Phase				Liquid Phase				Equilibrium Ratio		
	Pressure PSIA	Temp °F	CO_2	CH_4	C_2H_6	C_3^+	CO_2	CH_4	C_2H_6	Mol Wt	CO_2	CH_4	C_2H_6	Mol Wt	CO_2	CH_4	C_2H_6
			Mole Per Cent				Mole Per Cent				Mole Per Cent						
A	1742	38 0	11 00	72 39	3 68	12 93	10 00	81 20	3 20	20 63	9 53	36 12	4 79	98 37	1 049	2 248	0 668
A	1204	37 0	11 22	72 63	3 67	12 48	11 30	80 70	3 10	20 61	9 36	28 82	5 05	107 00	1 207	2 800	0 614
A	920	38 5	11 49	74 55	3 74	10 22	11 50	85 10	3 40	20 60	8 48	23 86	5 22	117 06	1 356	3 566	0 651
A	636	38 0	11 75	75 96	3 77	8 52	13 00	82 80	3 70	20 62	6 66	17 38	4 70	130 15	1 952	4 764	0 787
B	6762	36 0	6 04	79 71	3 89	10 36	6 04	83 65	4 09	24 60	5 85	66 49	4 23	60 43	1 031	1 258	0 966
B	5192	39 0	6 05	79 93	3 88	10 14	6 01	85 54	4 04	22 67	5 89	61 99	4 43	69 44	1 020	1 379	0 911
B	2959	38 0	6 08	80 61	3 84	9 47	5 80	88 00	3 90	19 92	5 48	51 06	4 83	87 20	1 058	1 723	0 807
B	2371	38 0	6 09	80 71	3 85	9 35	6 10	90 30	3 60	19 74	5 76	47 01	4 77	90 83	1 059	1 921	0 754
B	1336	38 0	6 12	80 30	3 80	9 78	6 30	90 00	3 60	19 33	5 39	34 40	5 65	109 00	1 169	2 616	0 637
B	872	39 0	6 17	80 47	3 70	9 66	6 40	88 80	3 40	19 48	4 33	24 72	5 11	123 55	1 478	3 592	0 665
B	749	38 0	6 17	80 11	3 73	9 99	6 00	89 40	3 50	18 65	4 26	22 09	4 91	128 84	1 408	4 047	0 713
B	631	38 0	6 27	80 54	3 73	9 46	6 40	88 10	3 70	19 20	3 76	19 46	4 63	133 27	1 702	4 527	0 799
A	8554	120 0	11 12	72 86	3 66	12 36	11 82	75 95	3 27	33 62	10 96	64 86	3 16	58 94	1 078	1 171	1 034
A	7052	120 0	11 12	72 95	3 67	12 26	11 82	78 08	3 68	28 07	10 63	63 51	3 65	64 27	1 112	1 229	1 008
A	5064	120 0	11 11	72 95	3 67	12 27	12 49	79 49	3 83	24 44	10 71	54 30	3 87	73 44	1 166	1 464	0 990
A	3241	120 0	11 11	73 28	3 68	11 93	11 65	81 47	3 58	22 35	9 65	46 39	3 86	87 36	1 208	1 756	0 927
A	2112	120 0	10 99	72 61	3 67	12 73	11 39	81 44	3 50	21 34	8 62	35 01	4 31	104 55	1 322	2 326	0 812
A	1319	120 0	11 37	73 32	3 75	11 56	12 00	83 20	3 70	20 74	7 35	24 98	4 22	107 52	1 633	3 330	0 877
A	786	120 0	11 64	75 32	3 74	9 30	12 20	82 80	3 70	21 73	5 70	16 31	3 22	141 56	2 140	5 077	1 149
B	6130	120 0	6 05	80 20	3 87	9 88	5 87	84 74	4 11	24 00	5 40	62 69	4 18	71 94	1 087	1 351	0 983
B	2691	120 0	6 09	80 86	3 84	9 21	6 20	90 00	3 80	20 17	5 21	45 31	4 44	97 96	1 190	1 986	0 856
B	1937	120 0	6 08	80 29	3 82	9 81		88 60	3 80	19 79		36 83	4 41	110 40		2 406	0 862
B	1541	120 0	6 13	80 96	3 76	9 15	6 50	88 10	3 80	19 74	4 36	31 93	4 36	120 33	1 491	2 759	0 872
B	642	120 0	6 36	81 98	3 69	7 96	6 60	89 40	3 80	19 70	2 53	15 04	2 81	156 98	2 609	5 944	1 352
A	7155	202 0	11 09	72 98	3 68	12 25	11 62	78 66	3 71	30 25	10 86	63 71	3 86	63 52	1 070	1 235	0 961
A	5047	201 5	11 06	72 82	3 68	12 44	11 64	81 48	3 72	24 91	9 73	54 77	3 86	77 21	1 197	1 488	0 964
A	3160	202 0	11 06	72 65	3 68	12 61	12 54	82 08	3 68	22 34	9 04	42 54	3 99	100 10	1 386	1 929	0 922
A	1820	202 5	11 27	72 28	3 77	12 68	12 10	82 60	3 90	21 80	7 50	28 81	3 77	108 87	1 613	2 868	0 967
A	1138	202 5	11 59	74 09	3 74	9 98	12 60	82 10	3 90	21 66	5 12	19 39	2 87	144 95	2 460	4 234	1 359
A	722	203 0	11 85	78 07	3 73	6 35	12 30	81 10	3 80	22 02	4 11	14 42	2 26	163 29	2 990	5 620	1 680
B	5439	202 0	6 08	80 61	3 84	9 47	6 09	84 68	3 73	23 65	5 49	59 60	3 86	79 12	1 109	1 421	0 966
B	3056	202 0	6 10	80 88	3 83	9 19	6 40	87 90	3 90	20 60	4 73	46 13	3 96	104 15	1 353	1 905	0 985
B	1607	202 0	6 10	80 70	3 74	9 46	6 00	88 20	4 00	20 33	3 67	29 21	3 38	133 97	1 635	3 020	1 183
B	616	202 0	6 56	84 89	3 73	4 82	7 00	86 80	3 80	20 31	2 00	14 60	2 02	166 84	3 500	6 034	1 881







presence of carbon dioxide up to 12 mole per cent in the composite composition has no effect on the *K* values of the hydrocarbon constituents. The data of Katz and Hackmuth[2] for methane and ethane are also plotted for comparison.

Two ranges of carbon dioxide concentration were studied to determine the effect of composition on the equilibrium vaporization ratio of carbon dioxide itself. Over the range of concentrations studied, 6 and 12 per cent, there appears to be no variation in the *K* values for carbon dioxide. This was also the case for carbon dioxide in a natural gas - distillate system.[4] As was anticipated from a previous study,[4] at pressures below the region of the convergence pressure of the system carbon dioxide is more soluble in a crude oil system (smaller *K* values) than in a distillate as is shown by the dot-dashed lines on Fig. 2 and 3. This is contrary to the behavior of methane which is less soluble (larger *K* values) in crudes than in distillates.

In order to obtain a working chart of carbon dioxide *K*'s, the curves on Figs. 1, 2 and 3 were cross plotted as the logarithm of *K* versus temperature for lines of constant pressure. (Fig. 8). At pressures below 600 psi, the chart is based on extrapolated data.

By calculating the mole fraction of vapor in the equilibrium cell at various pressures, Roland[7] showed that the temperatures of 120°F and 200°F were above the critical temperature of the mixture in the cell. Similar calculations made in this study agree with those of Roland. In addition, 38°F also is above the critical temperature of the mixture studied.

The curves of Figs. 4, 5 and 6 showing the molecular weight of the coexisting vapor and liquid phases at various pressures for the three temperatures studied appear to have a convergence pressure corresponding to the convergence pressure of the equilibrium vaporization ratios at their respective temperatures. The molecular weight corresponding to this convergence pressure might possibly provide a means of characterizing the mixtures in any correlation involving the convergence pressure.

SUMMARY

Equilibrium vaporization ratios have been determined for carbon dioxide in a natural gas-crude oil system for temperatures of 38°, 120° and 202°F and for pressures ranging from 600 to 8,500 psi. No significant variation was shown in the equilibrium vaporizations ratios of the hydrocarbons or the carbon dioxide itself for carbon dioxide concentrations up to 12 mole per cent in the composites. As was anticipated from a previous study, carbon dioxide is more soluble in a crude than in a distillate.

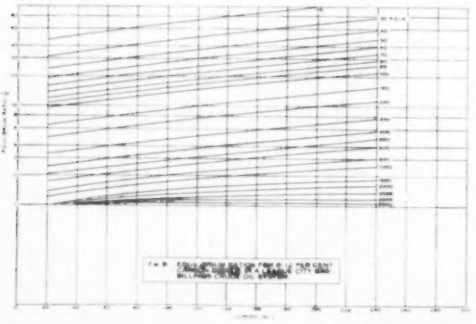


Table III — Molecular Weights and Specific Gravity for Trap Liquids

Specific Gravity 60/60 F	Molecular Weight
0.8616	242
0.8267	194
0.8541	228
0.8141	176
0.8455	215
0.7976	164
0.8360	198
0.8552	227
0.8147	186
0.8440	210
0.7946	154
0.8361	209
0.8309	194
0.8271	197
0.8253	190
0.8343	206
0.8296	193
0.8228	188
0.8321	200
0.8256	192
0.8203	188
0.8361	210
0.8469	232
0.8095	170
0.8420	224
0.7976	168
0.8497	229
0.8075	174
0.8327	207
0.8496	240
0.8044	168
0.8304	198
0.8342	202
0.8392	218
0.8412	197
0.8252	194
0.8302	198
0.8342	208
0.8242	189
0.8233	189
0.8216	185
0.8282	199
0.8376	207

These ratios, along with those determined for carbon dioxide in a distillate[4] and various binary mixtures of hydrocarbons[3,4] should provide a fairly complete picture of the vaporization characteristics of carbon dioxide in hydrocarbon mixtures.

ACKNOWLEDGMENT

The author wishes to express his appreciation to the management of Phillips Petroleum Co. for permission to publish this report; to Vernon Thornton and H. W. Rollman for their aid in the analysis of the gas samples and to Andrew F. Bertuzzi and other members of the Production Research Section of the Research Department for their aid during some of the sampling operations.

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FURTHER DEVELOPMENTS IN THE LABORATORY DETERMINATION OF RELATIVE PERMEABILITY

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ABSTRACT

An earlier publication has discussed three methods for obtaining relative permeability data on small core samples and the apparatus and technique for the capillary pressure displacement method. This paper describes the apparatus and technique for the solution gas and the dynamic displacement methods and presents a routine procedure for obtaining oil-gas and water-oil relative permeability data.

Theoretical and experimental considerations are presented to show that the end effect commonly associated with the dynamic flow mechanism is extremely small where constant rates are employed in the flowing phase. An effect of flow rate on relative permeabilities obtained by the dynamic system is found only when gas is one of the flowing phases and this effect is ascribed to a form of channeling in the capillary system.

The apparatus and procedures used to obtain relative permeability data with three phases flowing are described and some preliminary results of the use of this method are shown.

INTRODUCTION

In a previous publication from this laboratory there appeared a brief discussion of the concepts behind three basic methods for obtaining relative permeability data.[1] These three methods were called the capillary pressure displacement method, the solution gas displacement method, and the dynamic displacement method — the names being suggestive of the type of process used for obtaining the desired saturation prior to making the permeability measurements. In the same publication, the apparatus and technique for the capillary pressure displacement method were described and some typical results obtained by this method were presented. This paper will present:

1. The routine procedure used to obtain complete relative permeability data on small core samples with two phases flowing;
2. The experimental techniques for the solution gas and dynamic displacement methods for obtaining relative permeability data;
3. The results of some studies on the mechanism of fluid flow through consolidated porous media; and,
4. The preliminary results on the determination of relative permeability for a system in which three phases are flowing.

TECHNIQUE AND APPARATUS FOR THE DETERMINATION OF RELATIVE PERMEABILITY WITH TWO PHASES FLOWING

In order to obtain relative permeability data on a small core sample which will describe the various phases of reservoir depletion, it is necessary that the methods used duplicate, as closely as possible, the various mechanisms involved in reservoir depletion. It is important that, in any type of relative permeability determination, the core be originally at virgin reservoir conditions with respect to the fluids within the pore spaces, (for example, oil used to displace water from core until connate water saturation established), and that the subsequent saturation changes in the core be analagous to the reservoir depletion mechanism for which the data are to be used.

PROCEDURE OF DETERMINING RELATIVE PERMEABILITY DATA WITH TWO PHASES FLOWING

A standardized procedure has been set up for obtaining relative permeability data and other information on small core samples. This procedure essentially consists of 11 steps as shown below:

1. Determination of the capillary pressure curve.[2] This information is used to help select samples for relative permeability determinations and to characterize, in general, the pore size distribution of the sample.
2. Determination of the specific permeabilities to air, oil, and water. These values are those on which the relative permeability calculations are based.
3. Reduction of the core to connate water by an oil drive using the high speed centrifuge.
4. Determination of the critical gas saturation value and the associated relative permeability to oil by the solution gas drive method.
5. Determination of the relative permeabilities to oil and gas in the region where both phases are flowing by the capillary pressure method.
6. Reduction of the sample to residual oil in the centrifuge by an air drive, and the determination of the relative permeability to gas at this point.

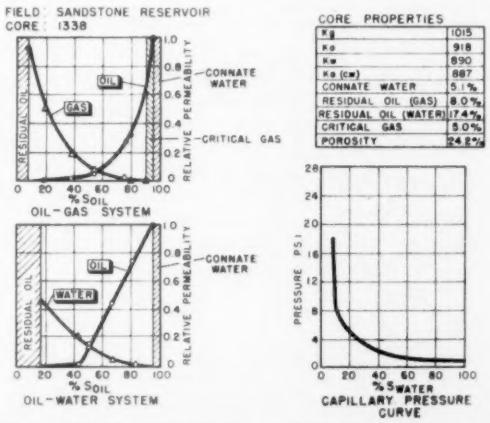

FIG. 1 — RELATIVE PERMEABILITY AND CAPILLARY PRESSURE DATA.

[1] References given at end of paper.

Manuscript received in the office of the Petroleum Branch August 10, 1950. Paper presented at the Petroleum Branch Fall Meeting in New Orleans, La., Oct. 4-6, 1950.

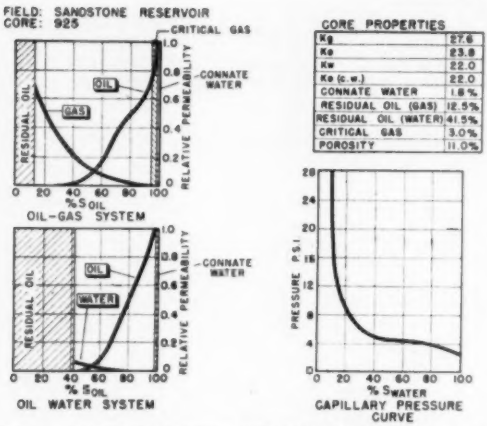

FIG. 2 — RELATIVE PERMEABILITY AND CAPILLARY PRESSURE DATA.

7. Analysis of the remaining fluid content of the sample to check the saturation determinations in Steps 4 through 6. This completes the study of the gas-oil flow system.

8. Reduction of the sample to connate water by an oil drive in the centrifuge — the same as in Step 3.

9. Determination of the relative permeability to oil and water by the dynamic method.

10. Reduction of the sample to residual oil by a water drive using the high speed centrifuge and the determination of the relative permeability to water at that saturation value.

11. Analysis of the fluid content of the sample to check saturation values obtained during the relative permeability determinations.

Some representative data obtained by the use of this procedure are shown in Figs. 1 through 4. The specific permeabilities to air, oil, and water, and the effective permeability to oil at connate water are shown for each sample represented. For reasons which were explained in a previous publication,[1] the base value used to calculate relative permeabilities is the specific permeability to water (of the appropriate salinity). Each of these sets of relative permeability data are close to the average data obtained for the fields represented, but do not necessarily hold for other reservoir materials even though the basic core properties (such as specific permeability, connate water, etc.) may be similar. A striking example of the individuality of relative permeability data is furnished by the data presented in Fig. 2. All of the samples from this field which have been studied exhibit the extremely high residual oil values with displacement by water and the low permeability to water at this point. Relative permeability data on other reservoirs of similar permeability have exhibited no such marked difference between the residual oil values for water and gas. This example also stresses the need for relative permeability data obtained on samples of the reservoir being studied since such peculiarities may occur in any system and cannot be predicted with present knowledge.

DESCRIPTION OF THE SOLUTION GAS DRIVE RELATIVE PERMEABILITY METHOD

The solution gas drive method, which is used to obtain the critical gas saturation value and the relative permeability to oil at that point, consists of allowing gas to evolve from solution by reducing the pressure on a core containing live oil and connate water. This evolution of gas creates a gas saturation within the sample which is a few per cent higher than the critical gas saturation value. This small amount of excess gas is then flushed from the pore space by a flow of dead oil at very low pressures and flow rates. This reduces the gas content to the critical gas saturation value. Normally two to three pore volumes of dead oil flushed through the core are sufficient to displace this excess gas. When the critical gas saturation value has been reached, this same flow of dead oil through the sample is used to measure the permeability to oil associated with this saturation. A schematic diagram of the apparatus used for these studies is shown in Fig. 5. The core sample, containing oil and connate water, is held in a Hassler-type core holder during both the measurements of permeability and the replacement of the original oil in place with live fluid. An initial effective permeability to oil at the connate water saturation is measured at atmospheric conditions by a flow of oil from the constant rate pump. The associated pressure drop along the core is measured by a Nullmatic Differential Pressure Transmitter (T in Fig. 5) having a measured differential pressure range of 5 to 50 in. of water.* Following this measurement the oil flow is stopped

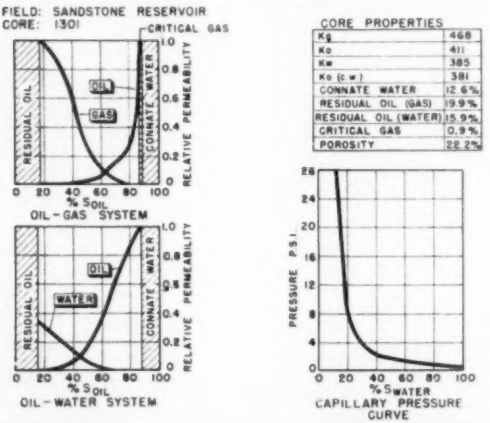

FIG. 3 — RELATIVE PERMEABILITY AND CAPILLARY PRESSURE DATA.

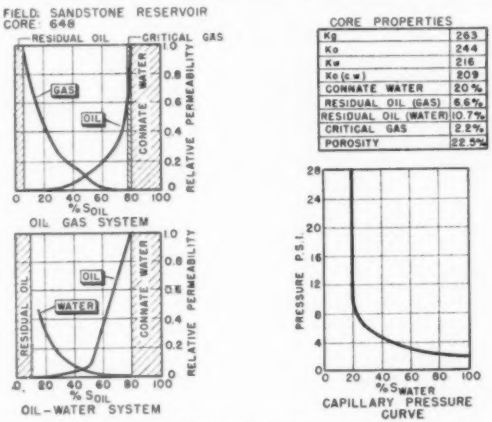

FIG. 4 — RELATIVE PERMEABILITY AND CAPILLARY PRESSURE DATA.

* Manufactured by the Moore Products Co., Philadelphia, Pa.

and the dead fluid in the sample is replaced by oil containing air in solution at approximately 30 psig pressure. The live oil reservoir serves for both mixing and storing the live fluid. In replacing the dead oil in the core sample with live fluid, the entire system (exclusive of the constant rate pump) is placed under pressure equal to the bubble point of the live oil by means of the pressure regulator NR-1 and the additional pressure necessary to induce flow of the live fluid through the sample is imposed upon the live oil reservoir with the air loaded regulator NR - 2. It has been found that a flow of 10 to 15 pore volumes through the core sample insures displacement of the dead oil originally in place. The portion of the flow system containing the sample is then reduced to atmospheric pressure to allow the gas to be evolved from solution. Several hours standing at atmospheric pressure is usually necessary for complete evolution of gas in consolidated sand samples, due to the resistance of the capillary system to bubble formation when relatively low pressure changes are involved. It has also been found that the evolution of gas in a small core plug (seven-eighths in. in diameter by one in. long) will only increase the gas saturation of that sample to three to four per cent of the pore space above the critical gas saturation value, even though there be several pore volumes of gas liberated in the pore space of the sample. This same phenomenon was found by other investigators in this field.[3] The flowable gas in the core sample is flushed from the pore space with a small (two or three pore volumes) flow of oil at a low rate from the constant rate pump. The displacement of this excess gas is followed by observation of the output end of the core and by the changing permeability to oil, which becomes constant when the critical gas saturation value is reached. The amount of gas then present is determined by comparing the weight of the sample submerged in oil with a similar weight obtained when the core contained no gas. Critical gas saturation values for the sandstone reservoir samples studied average two to three per cent of the pore space.

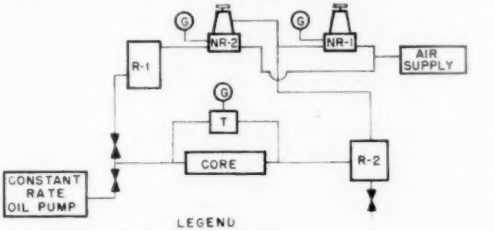
G
NR-2
G
NR-1
AIR SUPPLY
R-1
G
T
CORE
R-2
CONSTANT RATE OIL PUMP
LEGEND
R-1 LIVE OIL RESERVOIR
R-2 SEPARATOR TANK
NR-1 NULLMATIC PRESSURE REGULATOR (FOR DOWNSTREAM PRESSURE ON CORE)
NR-2 NULLMATIC PRESSURE REGULATOR (AIR LOADED - FOR UPSTREAM PRESSURE) IS LOADED WITH PRESSURE FROM R-2 AND MAINTAINS A CONSTANT PRESSURE DIFFERENCE ABOVE R-2
T NULLMATIC DIFFERENTIAL PRESSURE TRANSMITTER - TRANSMITS THE PRESSURE DIFFERENTIAL TO GAUGE G
G BOURDON TUBE PRESSURE GAUGE

FIG. 5 – SCHEMATIC DIAGRAM OF THE SOLUTION GAS RELATIVE PERMEABILITY EQUIPMENT.

DESCRIPTION OF THE DYNAMIC RELATIVE PERMEABILITY METHOD FOR A WATER-OIL FLOW SYSTEM

The dynamic displacement method is patterned after that described by Yuster, *et al.*,[4] and, essentially, differs only in the use of a Hassler-type core holder and constant rate positive displacement pumps to preset the desired flow rates. A schematic diagram of the equipment used is shown in Fig. 6. The core sample is placed in the center section of the three-piece

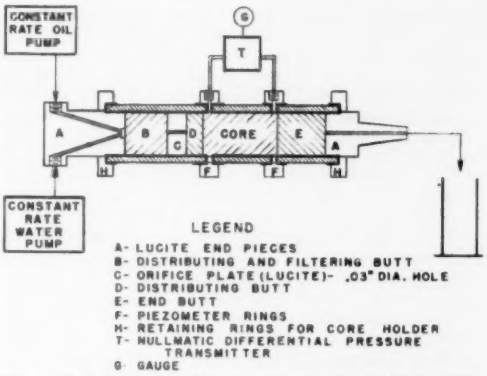

FIG. 6 – SCHEMATIC DIAGRAM OF THE DYNAMIC RELATIVE PERMEABILITY EQUIPMENT.

holder in such a manner that the ends extend beyond the pressure taps in the piezometer rings. The core is immediately preceded and followed by butt pieces of the same or similar material to distribute the flow across the face of the sample and eliminate any saturation gradient which might be caused by a boundary effect. These sections are also preceded by a premixing butt of loose porous material and an orifice plug made of plastic. This arrangement allows the pressure measurements to be made on the sample with no intervening core faces which might introduce errors into the measurements. The procedure used with this equipment in order to determine the relative permeabilities to oil and water is as follows. The core sample, saturated with oil and connate water, is placed in the apparatus and the effective permeability to oil at this condition is measured. A small flow of water is then introduced simultaneously with the oil to increase the water saturation in the core. The approach to equilibrium in this two phase flow system is followed by observing the changing pressure drop which stabilizes when the liquid saturations have become constant. This pressure and the preset flow rates allow the calculation of effective and relative permeabilities and the corresponding saturation is obtained by removing and weighing the core sample on an analytical balance. The sample is then replaced in the apparatus and further points on the relative permeability curves are obtained in the same manner using increasingly higher ratios of water to oil flow rates. The final point in this determination, with the sample reduced

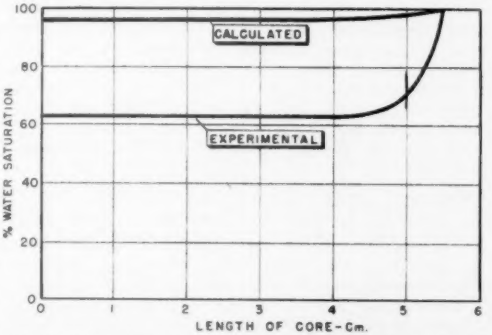

FIG. 7 – CALCULATED AND EXPERIMENTAL END EFFECT IN AN OIL-WATER FLOW SYSTEM.

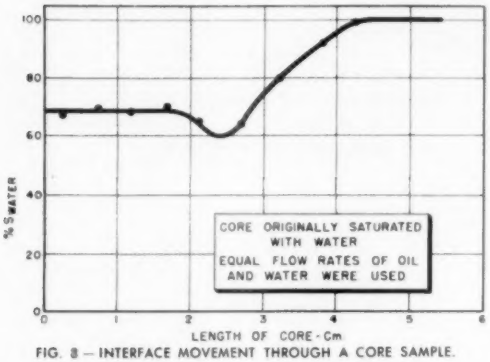

FIG. 8 — INTERFACE MOVEMENT THROUGH A CORE SAMPLE.

to residual oil by a water drive, may be obtained with this apparatus, but it has been found faster and more accurate to use the high speed centrifuge to obtain the saturation condition and then merely measure the effective permeability to water at this point. From these data, relative permeability curves such as those shown in Figs. 1 through 4 may be obtained.

STATISTICAL METHOD FOR AVERAGING RELATIVE PERMEABILITY DATA FOR A NUMBER OF SMALL CORE SAMPLES

It is recognized that when relative permeability determinations have been made on several samples from a petroleum reservoir, some method is needed for averaging these data to obtain a set of relative permeability curves which may be used in reservoir engineering calculations. The method to be described in this paper consists of a statistical averaging of relative permeability data from individual samples which have been placed on a directly comparable basis. With this method the relative permeability and the permeability ratio curves are plotted as a function of that portion of the total porosity in which simultaneous two-phase flow may take place (*i.e.*, that portion of the total porosity in which neither the k_o/k_o nor the k_w/k_o ratios are infinite). This eliminates the differences in these curves due to individual values of the connate water, residual oil, and critical gas saturations. In averaging these curves the greatest reliance is placed upon the experimentally determined permeability ratio curves since they, as a group, show less individual peculiarities than do the relative permeability curves. An essential aid is the use of a semi-logarithmic plot of the data instead of the conventional Cartesian coordinate presentation. Average saturation values are determined arithmetically at equal values of relative permeabilities and permeability ratios. The average curves are replotted on the basis of total porosity using average values for connate water, residual oil and critical gas saturations. This averaging method does not take into account such inhomogeneities in the reservoir as permeability streaks, channeling, etc.

MISCELLANEOUS STUDIES IN TWO AND THREE-PHASE FLOW SYSTEMS USING THE DYNAMIC DISPLACEMENT METHOD

In addition to the routine relative permeability work described, investigations are being carried out leading towards the understanding of the mechanisms of multiphase fluid flow in porous media and towards the development of other types of relative permeability determinations. The results of some of these investigations are discussed below.

Saturation Gradient Due to Boundary Effect In a Two-Phase Flow System

In order to study the possible effect of flow rate on relative permeability data obtained by the water-oil dynamic flow mechanism theoretically as well as experimentally, it was felt that the so-called end effect (a saturation gradient along the length of the core due to the absence of any pressure difference between the phases at the output face of the porous media being studied) would be the major cause of such a rate effect. A mathematical consideration of this problem utilizing Darcy's Law, relative permeability curves, and a capillary pressure curve resulted in the development of an expression describing the end effect in a water-oil flow system as shown below:

$$\frac{dp}{dl} = \frac{Q\mu}{kA} \qquad \ldots\ldots\ldots\ldots \quad (1)$$

where:

k = permeability (cm²) $\quad \mu$ = viscosity (centipoise)
Q = flow rate (cm³/sec) $\quad p$ = pressure (dynes)
l = length (cm) $\quad A$ = cross sectional area (cm²)

Darcy's Law holds for each phase in the flowing system. Subtracting the equation as applied to water from the equation applied to oil:

$$\frac{dp_o}{dl} - \frac{dp_w}{dl} = \frac{Q_o\mu_o}{Ak_o} - \frac{Q_w\mu_w}{Ak_w} \qquad \ldots \quad (2)$$

or letting $dp_o - dp_w = d(\triangle P)$ where $\triangle P$ is the pressure difference acting between the phases, transposing and integrating:

$$l = \int_{S_w = X}^{S_w = 1.0} \frac{A\, d(\triangle P)}{\frac{Q_o\mu_o}{k_o} - \frac{Q_w\mu_w}{k_w}} \qquad \ldots\ldots\ldots \quad (3)$$

where X is the lowest water saturation obtainable under the imposed flow conditions and would, therefore, be the equilibrium saturation value in any portion of the porous media where the end effect was non-existent. In Equation (3), l is

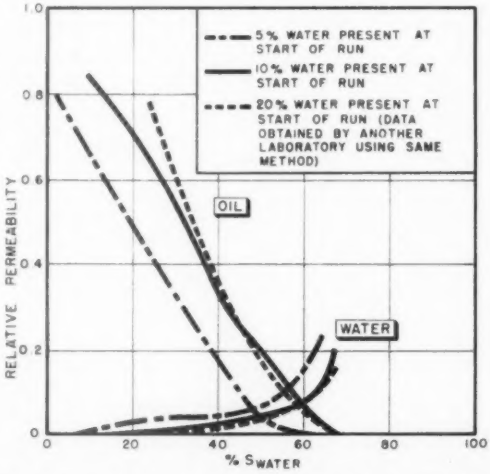
5% WATER PRESENT AT START OF RUN
10% WATER PRESENT AT START OF RUN
20% WATER PRESENT AT START OF RUN (DATA OBTAINED BY ANOTHER LABORATORY USING SAME METHOD)
OIL
WATER
RELATIVE PERMEABILITY
% SWATER

FIG. 9 — EFFECT OF VARYING THE ORIGINAL WATER SATURATION ON DYNAMIC RELATIVE PERMEABILITY.

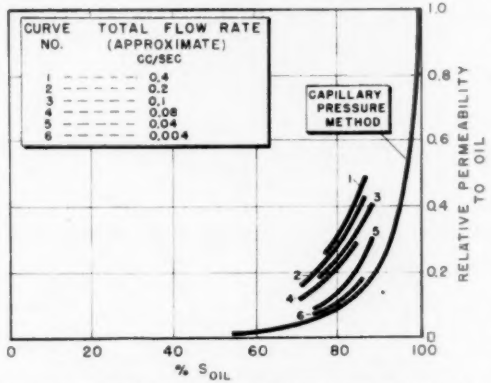

FIG. 10 — EFFECT OF FLOW RATE IN THE GAS-LIQUID DYNAMIC FLOW SYSTEM.

the distance from the output end of the core where a water saturation between X and 1.0 may exist. The relationship of S_w and $\triangle P$ is given by the capillary pressure curve; k_o and k_w may be given as functions of $\triangle P$ by combining the capillary pressure curve with the relative permeability curve.

By solving Equation (3) graphically for a system in which oil and water would flow in equal rates through a synthetic core material of fused alundum, a plot was obtained of the saturation distribution to be expected with this system. It may be seen from Equation (3) that the largest end effect is to be expected at low flow rates and where the wetting phase is displaced by a non-wetting phase since the $\triangle P$ for any given saturation would be larger where that saturation was approached by a drainage rather than by an imbibition mechanism. The calculations were made for these conditions and the saturation gradient calculated is shown in Fig. 7. To check these calculations experimentally, an alundum rod two cm in diameter and 5.5 cm long was cut into eleven 0.5 cm sections and was substituted for the core and end butts in the dynamic apparatus with Kleenex layers being placed between the sections to insure capillary contact. The conditions used in the calculations were followed with the flow rate being 0.00005 cu cm per second for each phase. When an equilibrium condition had been reached in the flow experiment, the segments were immediately separated and analyses of the fluid content of each were made. The saturation gradient thus obtained is shown in Fig. 7 along with that calculated from relative permeability data by the method described. A very striking discrepancy can be seen between these two curves in that the end effect which, according to the calculations, should have extended well through the entire length of the sample, was actually confined to the last cm of its length.

It was thought that this discrepancy might be due to the inapplicability of the drainage (capillary pressure) curve to the desaturating mechanism used since it had previously been found that high pressures were associated with non-wetting phase fronts moving through a core. To determine the mechanism of the movement of such an interface, a segmented alundum rod was again used in a dynamic flow system with oil and water flowing at equal rates into the water saturated sample. The rod was taken apart for analysis when the oil interface had progressed only three-fourths of the length of the sample. Analysis of the fluid content of the segments proved the saturation distribution to be as shown in Fig. 8. These results were reproduced using a different segmented sample (of larger diameter) and using gas as the non-wetting phase. These experiments led to the hypothesis that even at very low flow rates there is a large enough pressure gradient associated with a non-wetting phase interface movement to reduce the wetting phase saturation immediately behind this interface to a value lower than the equilibrium saturation value eventually established. This indicates that the equilibrium saturation in a two-phase flow system is approached by an imbibition rather than by a drainage mechanism in a constant rate dynamic flow system even though the wetting phase is being displaced by a non-wetting phase.

In order to check into this possibility more fully, the capillary pressure vs. saturation curve which would be necessary to calculate the experimentally determined saturation gradient was constructed from the experimental data. This curve was found to have the shape and general appearance of an imbibition rather than of a drainage-type curve and appeared quite similar to the imbibition curves described in the literature.[4]

Since, in the routine determination of relative permeability to oil and water by the dynamic method, an imbibition mechanism is used explicitly (that is, oil is displaced by water), the end effect encountered is also small. From the low flow rates mentioned above to flow rates three orders of magnitude higher there has been found no effect of rate on relative permeability data obtained with a two liquid flow system by the dynamic method.

The Effect of Initial Interstitial Water Saturation On Dynamic Relative Permeability Determinations

It has been found, however, that in the routine determinations of relative permeabilities to oil and to water by the dynamic method, the amount of water present as interstitial water at the start of the determination will materially affect the relative permeability data obtained. Fig. 9 shows this effect on a sandstone sample for which 10 per cent is the irreducible water saturation as determined by the high speed centrifuge method. It may be seen that not only the starting points, but also the actual configurations of the relative permeability curves vary with the amount of interstitutial water originally present. The magnitude of this effect for original water saturations varying from 5 to 15 per cent is shown by the curves in Fig. 9. It is felt that, except for special studies, the amount of water present at the start of a relative permeability determination should be the irreducible water saturation of the sample.

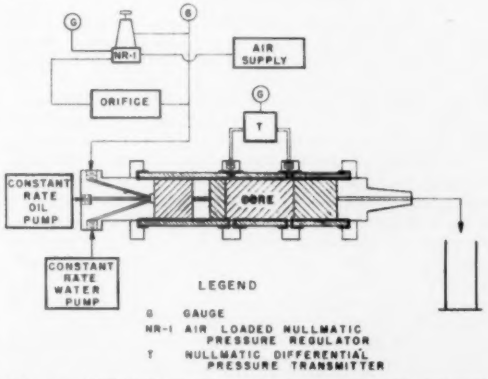

FIG. 11 — SCHEMATIC DIAGRAM OF THE THREE-PHASE DYNAMIC FLOW EQUIPMENT.

The Dynamic Flow System Using Gas and Liquid As the Flowing Phases

In a two-phase dynamic system where gas is one of the flowing phases, there is a definite effect of flow rate on the resulting relative permeability data. This effect is in the direction of decreasing the permeability to both phases with decreasing total flow rates. This effect is demonstrated by the experimental results shown in Fig. 10. The relative permeability to gas behaves in a similar manner, but is not presented in order to avoid confusion in the figure. Also shown is the relative permeability to oil curve for this sample obtained by the capillary pressure method. It may be seen that at the lower rate shown the relative permeability to oil is close to, and within experimental error of, that curve obtained by the capillary pressure method. Determinations at each of these flow rates were made with the segmented alundum rod and the results indicated that no end effect was present in any of these determinations to account for this effect of rate. It seems likely that the increase in effective permeability to each phase with increasing flow rates is due to a form of channeling caused by the high velocities of the gas flowing through the capillary system. A high velocity gas flow through a capillary system can sweep the oil phase from restrictions in its path which would normally be closed to the flow of gas and at the same time carry a portion of the oil phase through the core as droplets in the gas phase, and thus increase the permeability to each phase. Such a phenomenon in a gas-oil flow system has been observed in microscopic studies of an unconsolidated porous system. In a previous publication,[1] the opinion was expressed that relative permeability data obtained by the capillary pressure and the dynamic methods would differ due to the different displacement mechanisms involved. On the basis of recent work, such as that described above, it is now felt that the two methods will give similar results for gas-oil flow systems. However, the flow rates necessary to eliminate the effect of rate for a gas-oil system in the dynamic method are so low that the use of this method as a routine tool for obtaining relative permeabilities to gas and oil is impractical because of the length of time required to reach an equilibrium value. This conclusion is based primarily on data obtained in experiments in which only oil and gas were present. A small amount of experimental data suggests that it may be modified if connate water is present during the determination.

RELATIVE PERMEABILITY DETERMINATIONS WITH THREE PHASES FLOWING SIMULTANEOUSLY

Using the gas-liquid two-phase study as a guide for the flow rates necessary in the gas phase, some preliminary work has been done in setting up and studying a system in which three phases flow simultaneously. A dynamic method was chosen because of several experimental difficulties which may be foreseen in the use of the capillary pressure method for this work. The only modification necessary was the addition to the regular two liquid dynamic apparatus of a metering device to produce a constant flow rate of gas through the sample under study. A schematic diagram of the apparatus in use is shown in Fig. 11. The gas metering device shown in the upper left hand corner consists of an air loaded pressure regulator and a very tight core plug which is used as an orifice. The spring load of the regulator (NR-1) is set to the pressure which will give the desired flow rate through the core plug (orifice), and this pressure differential is held, regardless of the buildup of back pressure in the fluid flow system, by the air loading feature of the regulator. The core sample under study is handled as in the two liquid dynamic system except that it has been necessary to analyze the fluid

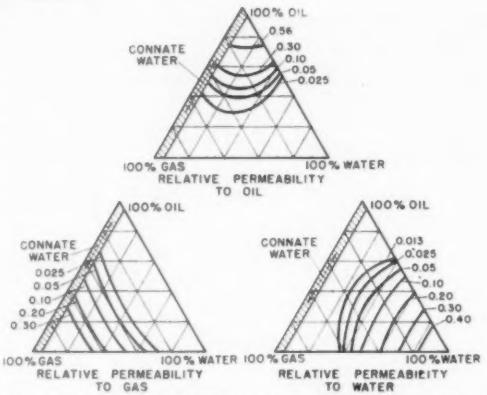

FIG. 12 — RELATIVE PERMEABILITY OF A THREE FLOWING PHASE SYSTEM.

content of the core by vacuum distillation after the determination of each point in order to obtain a saturation value. Since the flow rates must be low in order to avoid an effect of rate due to the presence of gas, from two to five days have been necessary to reach an equilibrium value on each point determined.

As yet, not enough three-phase data have been gathered on a single sample to permit a complete description of the resulting relative permeability characteristics. However, Fig. 12 shows the results obtained to date upon a consolidated sandstone sample. The isoperms for gas and oil agree in general configuration with those presented in the literature.[6] However, where these earlier investigators found the relative permeability to water to be dependent only upon the water saturation, it has been found in this case that the water permeabilities as well as the gas and oil permeabilities are dependent upon the saturations of all three phases. These data, as presented in Fig. 12, are obtained when the sample under study originally contains oil and connate water and the oil content is decreased by simultaneously increasing the water and gas saturations. A form of hysteresis has been observed when the oil saturation in the core is increased after originally being reduced to connate water and residual oil with a gas drive. The relative permeabilities to all three phases are decreased in this case below those observed when the core originally contains oil and connate water. Obtaining a complete relative permeability history with three phases flowing on a single core sample by this method will necessarily require a long period of time, but it is felt that such data will be extremely useful in calculating field performance for reservoirs being produced by simultaneous water and gas drives, by water drive on a partially gas depleted field, etc.

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T.P. 3059

MINERALOGICAL STUDIES OF CALIFORNIA OIL-BEARING FORMATIONS

I—IDENTIFICATION OF CLAYS

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ABSTRACT

A progress report of an experimental investigation into the role of clay in reservoir performance is presented. The paper gives some of the reasons for considering clay as a significant component and outlines the objectives of a broad field of study which it is intended to pursue. Descriptions of the analytical methods used are given; these include X-ray diffraction, electron miscroscopy, thin section petrography, infrared spectroscopy, and cation exchange analysis. A suite of the more important clay minerals has been assembled and characterized by these methods for use as standards in core analysis. From the data obtained it appears that although no one method of analysis is diagnostic for all of the clay minerals the infrared technique shows considerable promise in this direction. For the present, one or more supplementary methods should be used to confirm the clay mineral identifications.

The methods of analysis are applied to field cores taken from representative and widely differing strata especially as regards their susceptibility to damage by fresh water. Wells completed in the Stevens and Gatchell Zones in San Joaquin Valley are particularly clear-cut examples of this behavior with Stevens Zone wells being more adversely affected by fresh water. Cores from these zones have been studied and are discussed. It appears that differences in this behavior can be ascribed to differences in the nature of the contained clays. The value of the infrared spectra of the clay fractions in establishing the identity of the predominant clay minerals is given particular emphasis.

INTRODUCTION

It is a challenge to the technical resources of the petroleum industry that when the economic limit of production is reached, from 40 to 70 per cent of the oil in California reservoirs remains unproduced even by use of the best presently known methods of recovery. The magnitude of this abandoned volume of oil can be appreciated when it is considered that to 1950 in excess of 8 billion bbl[1] has been produced from California reservoirs with estimated economically recoverable reserves in known fields and pools totaling nearly 4 billion bbl.[2] If for every barrel of oil produced there is at least another barrel still in place, it is evident that the revenue obtained from the recovery of only a few per cent of this volume would repay the cost of the required research manyfold.

From well completion experience, production behavior, and a growing body of laboratory data it now appears certain that the mineral composition of a producing stratum has an important bearing on the productivity and ultimate yield. In addition to the organic component and water, the cores consist of gravel, sand, silt, and clay* in diverse variety of (a) composition and (b) texture. It is the composite effect of these two factors which is probably responsible in large measure for the way in which the oil flows to the well. The role of the clay and fine-size accessory minerals is not clear but there is a growing opinion, based on their physical and chemical properties, that it is a significant one. Of particular importance are the prime facts:

1. The silt and clay fractions of the reservoir matrix possess the highest surface area per gram, and

2. The silt and especially the clay fractions are the most chemically reactive of the inorganic constituents present.

Only within the last few years has the knowledge of clay mineralogy and the techniques of identifying the clay minerals reached such a stage as to enable reliable inquiry into the composition of argillaceous sediments.[7,8,10,11,12,16,20] It is the purpose of this and succeeding papers to add to the fund of information on the role which these materials play in the production of petroleum from California formations by correlating their presence and associated properties with observed reservoir behavior. In the present paper attention is directed to their possible influence on damage by fresh water.

OBJECTIVES

The attack on this problem divides naturally into two broad phases:

1. Determination of the nature of the clays and their relationships to the other mineral components, and

2. Determination of the physico-chemical relationships between the clays and the interstitial fluids.

In the work described in this paper the emphasis has been on Phase 1, which stems logically from the necessity of identifying and understanding the materials to be dealt with in Phase 2.

Based on the authors' present opinion that not all of the minerals which occur in oil-bearing formation are of equal importance in their effects on the flow and recovery of oil, it was decided to focus attention first upon the clay minerals content and then, later perhaps, work into the field of the normally larger size non-clay minerals and fractions. The

[1] References given at end of paper.

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*The grade scale used is that of the U. S. Bureau of Soils.[22]

Table I — Descriptions of Reference Clays and Associated Minerals

Designation and Source Locality	X-Ray Diffraction, Phases[a] and Three Most Intense d Reflections, Å	Resume of Petrographic Analysis	Description of Electron Micrograph	Infrared Absorptions, μ[a]	Cation Exchange Capacity[b]
"Wyoming" Bentonite Sodium Montmorillonite (Belle Fourche, S. Dak.)	Montmorillonite, Quartz (minor) 11.0 4.46 1.49	platy to fibrous crystals, scattered grains of quartz and feldspar partly altered to montmorillonite	platy to amorphous, tenuous background		74
"Wyoming" Bentonite, Coarse Colloid, 40D2[c] (Belle Fourche, S. Dak.)	Montmorillonite 12.5 4.46 1.49		aggregates of plates, less amorphous than unfractionated clay, fine particle background	2.8 6.1 6.6 6.9 9.6 11.0 12.6	86
Nontronite (Last Valley Damsite Tamarack, Idaho)	Nontronite 14.9 4.54 1.53	resembles montmorillonite even to aggregate index although about 5% of pellets are of index higher than balsam; most of sample may not be the usual nontronite	more fine particles and diffuse background than montmorillonite		
Nontronite (Garfield, Washington)	Nontronite 14.9 4.54 1.53		generally subhedral to anhedral but with occasional laminar stacking and lath-like development	g	90
Hectorite (Hector, San Bernardino County, California)	Hectorite 11.8 4.53 3.15	similar to Na- and Ca- montmorillonite	faintly striated glassy anhedral laths	2.8 6.1 7.0 9.9	154[d]
Illite (Native "Grundite") (Goose Lake, Grundy County, Illinois)	Illite Quartz (minor) 10.2 4.48 2.58	superficially resembles montmorillonite, but aggregate index above balsam; minor amounts quartz, feldspar, apatite (?)	like montmorillonite but of more sharply crystalline laminarity	2.7 6.1 7.0 9.7 12.6 12.9	16
Illite (from Fithian Shale) (Fithian, Vermilion County Illinois)	Illite Quartz (trace) 10.2 4.48 2.58	relatively large (0.2-0.3 mm.) transparent crystals, positive elongation, aggregate index above balsam, nearly uniform extinction under crossed nicols	more homogeneous than "Grundite", gives appearance of a "euhedral montmorillonite"		35[d]
Muscovite (Spruce Pine (?), North Carolina)	Muscovite (major) Kaolin(?) (minor) 9.93 4.43 3.32	0.01 mm. grains, oriented cleavage faces, index, birefringence, elongation, extinction standard for muscovite	crystalline, micaceous, irregular aggregates tending toward conchoidal fracture, of particle size several orders larger than montmorillonite or illite	2.7 3.1 6.12 6.66 7.4 9.7 10.9	<1
Muscovite (Unknown)	Muscovite (major) 10.0 4.46 3.33		small rounded "pebbles" type particles very different from North Carolina muscovite		<1
Kaolin ("Hydrite Clay") (Georgia, U. S. A.)	Kaolin, Quartz (minor) 7.2 4.45 3.50	grains and tiny flakes (1-2μ), too small to resolve optical characteristics, indices appear higher than balsam, birefringence low	characteristic euhedral hexagonal and pseudohexagonal platelets	2.7 8.9 9.6 9.90 10.7 11.0 12.6 13.2	3
Anauxite (Tesla, California)	Kaolin, Quartz (minor) 7.2 3.58 1.48	majority grains and pellets <0.15 mm. diam.; smaller grains colorless, clear in transmitted light; aggregate index above balsam; birefringence in low grays, platy to fibrous crystals, pos. elongation	larger aggregates irregular but smallest flakelets show typical euhedral hexagonality	2.7 8.9 9.6 9.9 10.7 11.0 12.6 13.3	~3
Halloysite ("White Clay") (Eureka, Utah)	Major (?)[e], Illite (minor), Quartz (trace) 4.39 2.56 1.47	sample may be impure; 60-75% is colorless, amorphous, index above balsam (halloysite?), 15-20% of grains similar to Ca-montmorillonite; other grains suggest allophane, kaolinite	acicular, tubular, cylindrical, bilaminar, rather uniform size distribution when dispersed	8.9 9.6 11.0	6-10[d]
Halloysite (Lawrence County, Indiana)	Major (?)[e] Kaolin (trace) Quartz (trace) 4.83 4.39 2.45	aggregate index above balsam, medium to weak birefringence, may not be same form of halloysite as Eureka clay	similar to Eureka, Utah, halloysite		6-10[d]
Allophane (Lawrence County, Indiana)	? 5.72 3.49 2.94	clear, colorless practically isotropic (amorphous), elastic grains, tendency toward conchoidal fracture; index below balsam, optically resembles volcanic ash; few grains montmorillonite, kaolinite (?)	subhedral to anhedral, some tendency toward 120° angularity	g	
Talc (Johnson, Vermont)	Talc (major) (?) (minor) 9.42 3.13 4.53	platy to linear cross-sections, high index, high birefringence, parallel extinction, pos. elong., neg. uniaxial interference, talc confirmed	massive flat plates of irregular shape with sharp edges and points	g	~0
Pyrophyllite (Staley, North Carolina)	Pyrophyllite (major)[f] Quartz (major) 9.3 4.44 3.07	same general optical character as talc but with interference figure of large axial angle of ca. 60° (talc angle very small, muscovite ca. 40°)	platy, laminar, crystalline, with some very thin individual lamellae	8.9 9.4 10.6	~0
Feldspar ("Bainbridge") (Unknown)	Feldspar (major)[f] Quartz (major) 4.03 3.19 3.67	pure potash feldspar, absence of microcline twinning, neg relief; grain size 0.03-0.10 mm.; approx. 2% quartz (pos. relief)	angular, irregular, coarsely crystalline, some platy elongation	g	~0

[a] These are absorptions which after further study may prove to be of diagnostic significance.
[b] Approximate, in milliequivalents per 100 grams.
[c] Fraction sedimented in a Sharples Supercentrifuge bowl of 4.45 cm ID and 19.76 cm in length at 40,000 rpm using Drag No. 2 (flow rate of 725 ml per minute).
[d] Based on comparison with the ASTM Alphabetical Index of X-ray Diffraction Patterns (Covering Original Set of Cards), June, 1945, and (Covering the First Supplementary Set of Cards), August, 1945; Philadelphia.
[e] X-ray diffraction pattern is not in complete agreement with the data of ASTM Index for materials designated as halloysite. However, the halloysite of this investigation gives the same electron micrograph as do the halloysites taken from a number of widely scattered localities and illustrated in a recent API Project No. 49 report.[5]
[f] Both components estimated to be present in nearly equal amounts.
[g] Insufficient observation.

particular problem set was the identification and quantitative determination of the clays extracted from a carefully selected group of Union Oil Co. cores taken from seven wells in four California fields.

In order to obtain reliable identifications of the clay minerals it was necessary to assemble a suite of clay reference standards with which to compare the clay fractions separated from the cores. For this purpose 22 reference clays and associated minerals, a representative group of which is described in Table 1, were collected and characterized by the analytical techniques described below. Unfortunately, and solely because of unavailability of the necessary equipment, the differential thermal analysis method was not used. It should be mentioned that this reconnaissance survey was begun before the appearance of the excellent reports published by API Project 49 and others[21,29,23] on clay mineral standards.

ANALYTICAL METHODS

X-Ray Diffraction

The X-ray equipment consisted of a standard General Electric XRD unit fitted with Debye-Scherrer cameras. Copper radiation was employed.

The samples were prepared by crushing the material to pass a 100-mesh screen and then pressing the powder into a metal wedge supplied with the G.E. oscillating type holder. Developing and fixing procedures were standardized to permit film intercomparison.

Electron Microscopy

The micrographs were taken at 7,200 diameters with an RCA type EMU 50 kv electron miscroscope and subsequently enlarged to X45,000. The best resolutions obtained varied from 20 to 70 Å.[20] The scale on all figures is 1μ. Specimens were prepared and transferred to the instrument according to conventional procedures.[25]

In order to ensure selection of most representative fields the following specifications were adhered to: 10 different fields on two plates of five frames each were taken. A minimum of six photographically acceptable frames, two or more of which satisfied the requirement of being most representative was used for each sample. Pairs of plates were taken until these standards were met. Two plates were usually sufficient. To be acceptable a frame had to show adequate dispersion, contrast, focus, and be either generally representative of the specimen or reveal in detail some especially interesting feature.

Thin-Section Petrography

The clay reference samples were examined in the form of standard "grain" slides and in some cases as a single "smear."

The core chips were impregnated with shellac, ground with kerosene as lubricant and mounted on glass with Lakeside 70 cement. The finished sections were covered with Canada balsam and examined in the petrographic microscope.

Cation Exchange

Two methods for determining base exchange capacity (BEC) were used. Both were taken from the literature and then modified to suit the amounts of materials available.

Saturation with Ammonium Ion

As finally adopted the method for samples of one gram or more was a combination of the University of Wisconsin[7] and University of Illinois procedures.[4] Twenty-five ml of 1*N* ammonium acetate was added to the dried one-gram sample and shaken at intervals for one hour. The clay was centrifuged, washed once with 1*N* ammonium acetate and four times with neutral ethyl alcohol. The washings were poured through paper filter supported by a stainless steel wire funnel. Finally the clay was transferred to the filter and washed with 150 ml of ethyl alcohol to remove the last traces of NH_4^+ and the analysis completed by semi-micro Kjeldahl.

Colorimetric Manganese

Where the total amount of separated clay fraction was less than one gram and was required for several other types of analyses it was necessary to use a semi-micro method of BEC analysis. Starting with the procedure of Bower and Truog,[2] saturation replacement of the cation exchange ions with Mn^{++} and the colorimetric determination of the latter as MnO_4^-, the following modified procedure was developed:

Thirty ml of 1*N* $MnCl_2$ was added to the ground dried sample and shaken until the clay was dispersed. The mixture was allowed to stand for 16 hours to effect the exchange. Using centrifugation-decantation the sample was washed with two additional 30 ml portions of 1*N* $MnCl_2$ and finally with 30 ml portions of neutral ethyl alcohol until chloride-free. The sample was transferred quantitatively to a 400 ml beaker and 20 ml of concentrated sulfuric acid was added. Wet oxidation of all residual organic matter with about 5 ml of hydrogen peroxide was effected on a hot plate until the supernatant liquid was clear. The sample was diluted to 150 ml, filtered and washed with 100 ml of water. Two-tenths gram of para sodium periodate was added to oxidize the Mn^{++} to MnO_4^-. The volume of the sample was reduced to 175 ml at just below the boiling point, transferred to a 250 ml volumetric flask and diluted to the mark. The optical density was determined at $\lambda = 526$ mμ with a Model DU Beckman spectrophotometer. The BEC was calculated from graphs made with standard solutions.

The amounts of manganese present in the reference clays as determined by emission spectra were negligible, *e.g.*, <0.001 per cent in montmorillonite and <0.01 per cent in illite. No spectra were taken of the core clays.

With the approximately 0.1-gram samples the precision is about ±5 per cent in the montmorillonite range of BEC values and ±10 per cent for the very low values in the kaolin range.

Infrared Spectroscopy

It has been shown[5,6] that uncalcined montmorillonites exhibit characteristic absorptions in the infrared at 2.75μ and 2.92μ, attributed, respectively, to vibrations of unbonded or free hydroxyl (lattice or structural *OH*) and to hydrogen bonded (surface and interlayer hydration water) hydroxyl, *O:H:O*. This interesting observation suggested that infrared analysis might be used to differentiate the various clay reference minerals on the basis of these or some other characteristic absorptions. Moreover, the results of a number of clay analyses indicated the entire near infrared spectrum from 2 to 15μ to be of diagnostic interest.

Because experience showed that in some cases the larger particles gave less definitive spectra the clay was first fractionated by means of a Sharples Type 1A supercentrifuge to yield a colloid fraction of average particle size 0.1 - 0.06μ in radius.[7] The fine fraction was then suspended in three different concentrations, *viz.*, 0.1, 0.05, 0.01 gram of clay in 10 ml of 0.001*N* aqueous ammonia. It was necessary to use these three concentrations in order to cover the wide range of absorptions encountered in the 2 to 15μ region. The suspensions were deposited by means of a dropper on a single crystal silver chloride (Harshaw Chemical Co.) cell window to cover com-

pletely the area traversed by the beam. The cell window and suspension were then placed in a vacuum oven, dried at 50°C, removed and scanned in a research model of the Beckman IR-2 infrared spectrophotometer.

The per cent transmission versus wavelength graphs were plotted for each of the sample thicknesses in its particular spectral region and then joined in a continuous spectrum by moving the ordinates up or down as required for continuity. This results in a spectral curve which is qualitative in the sense that it shows the location of characteristic absorptions, gives the general spectral pattern, but does not enable accurate comparison of the relative magnitudes of the peaks obtained at different sample thicknesses.

It is, of course, realized that this is not orthodox infrared technique but for the purpose of a preliminary qualitative comparison of the different clay minerals it has proved adequate in demonstrating gross spectral differences. Thus, all of the major peaks are reproducible, although because of errors in the manual conversion of the original energy transmitted versus wavelength graphs to per cent transmission vs. wavelength plots some differences occur in regard to the minor peaks.

RESULTS AND DISCUSSION OF THE ANALYTICAL METHODS

X-Ray Data

On the basis of patterns obtained in this work it appears that:

1. The three strongest lines generally used to characterize montmorillonite and illite in massive form may not be completely diagnostic when applied to materials undergoing diagenetic alteration.
2. It is generally difficult to distinguish montmorillonite, nontronite and hectorite from one another without employing more refined techniques.
3. Kaolinite and anauxite cannot be distinguished with certainty.
4. The sodium, calcium, and cadmium exchange salts of a given montmorillonite yield essentially the same diffraction patterns. This might be expected on the basis that the replacement of one set of external exchange ions by another can occur without perceptible alteration of the arrangement of the lattice ions.
5. The three important sodic, potash, and calcic feldspars are not readily distinguished from one another by X-rays alone.

Electron Micrographs

Examination of the electron micrographs showed the rather wide diversity of structural habits which these minerals possess. Some of these habits are so distinctive that they are diagnostic by themselves, such as in the cases of kaolinite and halloysite. However, in general, the electron micrographs were not diagnostic and must be interpreted with caution. Thus, two different samples of muscovite strikingly dissimilar electronmicrographically gave identical X-ray diffraction patterns.

Petrographic Data

The data from the petrographic optical analyses as given in Table 1 are mainly of value as confirmatory evidence for identity as revealed by the other methods used. In the case of the feldspars, however, it is particularly clear-cut even to the extent of distinguishing between microline and orthoclase which are identical chemically but have different optical properties.

Cation Exchange Data

The cation exchange capacities supplement the other data of Table I in the sense that there are indicated no inconsistencies with the exchange capacities normally obtained for these materials. Thus, should the X-ray and electron micrograph data raise some question as to whether the Garfield, Washington, clay mineral is nontronite or illite, the cation exchange capacity of 90 milliequivalents per 100 grams would be good evidence against the latter. This follows from the well-known fact that the montmorillonites have cation exchange capacities in the range 60-120, the illites in the range 15-40 milliequivalents per 100 grams.

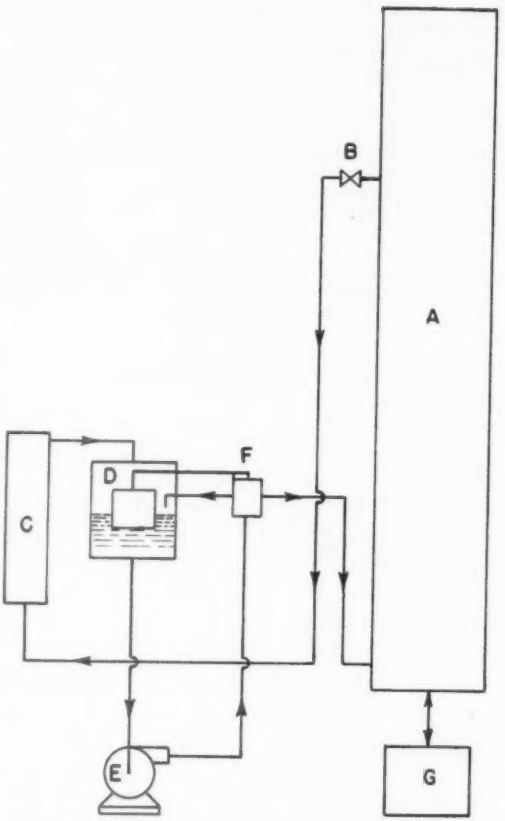

FIG. 1 — SCHEMATIC FLOW DIAGRAM OF CLAY SEPARATOR. A — ELUTRIATOR, B — "O"-RING SHUT-OFF VALVE, C — SUPERCENTRIFUGE BOWL, D — FLOAT ASSEMBLY, E — PUMP, F — "O"-RING FLOW REGULATOR, G — VIBRATOR-DRIVE MOTOR.

Chemical Data

Although no assemblage of chemical data is reported here chemical analysis has been useful in the characterizations of some of the reference minerals. Both emission spectrographic and standard chemical tests were employed. Examples of cases in which chemical data may be confirmatory are in the determination of K_2O content in illite and of high iron in nontronite. An example in which chemical analysis may be the deciding factor is the differentiation of anauxite from kaolinite on the basis of a silica:alumina ratio of 3:1 for the former and 2:1 for the latter.

Infrared Data

The most interesting aspect of the spectra is that in overall configuration as well as in regard to specific absorptions they are all apparently significantly different from one another. This observation raises a question of the highest importance for those concerned with the accurate identification of the clay and related minerals: can the infrared absorption spectra of these inorganic materials serve to differentiate readily and accurately the various minerals of very similar lattice structure which now require the use of more than one of the previously mentioned methods of analysis? It would appear from the data obtained that the answer may be in the affirmative. The results should be considered, however, as only preliminary in nature. Further work is necessary to isolate the effects on the spectra of such factors as degree of uniformity of particle size, nature of the exchange ions, the role of various impurities, role of isomorphous replacement within the lattice, etc.

ANALYTICAL SUMMATION

From the foregoing, it appears that although no one method of analysis is diagnostic for all of the clay minerals the infrared technique shows considerable promise in this direction. For the present, however, one or more supplementary methods should be used to confirm the clay mineral identifications.

ANALYSES OF NATURAL CORES

Core Samples

The core samples from the Dominguez, Paloma, Rosecrans, and Northeast Coalinga Fields, all of which were taken with oil base drilling fluid, are listed and described in Table II. They were of the conventional type 2½ in. in diameter and cut away to approximately 2 in. diameter before disaggregation in order to remove possible drilling mud infiltration. The cleaned cores were reduced (but not pulverized) to grain size, leached in toluene, then dioxane and dried.

Fractionation Equipment and Procedure

The separation and fractionation procedure employed, aside from the type of equipment, was essentially that developed by Bray, Grim and Kerr[7] except that the separation process was made continuous. This change in operating procedure from batchwise to continuous separation of the clay from the non-clay components proved advantageous in that the yield of clay was greater and the time required to achieve maximum separation was materially shortened.

The isolation of the clay fractions involved two major steps.

1. Separation of the total clay component, and
2. Size-fractionation of the total clay component.

The arrangement of apparatus used to accomplish these steps is illustrated in Fig. 1. In Step 1 two kilograms of leached and disaggregated core was charged to a mechanically vibrated Lucite elutriator *A* containing three gallons of dilute aqueous ammonia, the vibrator-drive motor *G* was started, the Sharples Type 1A air-driven supercentrifuge was set at 40,000 rpm with Drag No. 3 (largest nozzle size: 1,200 ml per minute flow rate), valve *B* was opened and pump *E* was started. The float assembly *D* and constant flow rate regulator *F* ensured constancy of particle size range and enabled uninterrupted operation of the elutriator through the by-pass arrangement provided by *F*. After eight hours of continuous cycling the centrifuge bowl *C* was emptied of its clay content. The operation was continued for a period of several days until after the last eight-hour period the bowl was empty.

Step 2 was carried out by suspending the total clay component in three gallons of dilute ammonium hydroxide solution and passing it through the supercentrifuge at different flow rates and speeds of rotation. This step, of necessity, was not continuous and involved the use of only the centrifuge part of the separator assembly. To assure no loss of fine fraction the effluent from each run was re-used as suspension medium for the succeeding run. The conditions for the individual separations are described in the footnotes to Table IV.

RESULTS OF CORE ANALYSES AND DISCUSSION

The various fine fractions obtained from the cores were subjected to examination by X-ray diffraction, electron microscopy, infrared spectroscopy and in some cases, when the amount of material available permitted, to chemical and cation exchange analysis. The petrographic thin section analyses were performed on the unseparated cores (Table II). In general, the silt fraction varied from 2 to 10 per cent and the total colloid fraction from 0.1 to 2 per cent by weight of the air-dried cores.

Table II — Descriptions of Cores

Field	Zone	Age	Relative Sensitivity to Fresh Water	Carbonate Content, %	Resume of Petrographic Analysis (Compositional)
Dominguez	3	Pliocene	—	2.62	Ca. 60% feldspars, chiefly orthoclase, 25-30% quarts 10-15% muscovite, altered biotite and accessories; feldspar alterations very fine-grained may be mainly sericitic with lesser kaolin.
Dominguez	3	Pliocene	—	2.71	Similar to preceding; relatively large concentration of "heavy minerals" as hornblende, pyroxene, epidote, apatite, etc.
Paloma	Stevens	Upper Miocene	+	0.74	Mainly quarts, feldspars of sericitic alteration; fine-grained dust may be kaolinitic; biotite, chlorite.
Dominguez	Lower 7	Miocene	+	2.04	Ca. 30% quarts, 60% sericitically altered orthoclase, microcline, sodic plagioclase feldspars, kaolin (?); remainder is muscovite, biotite, apetite, zircon, etc.
Dominguez	Upper 8	Miocene	+	2.17	Mainly altered (to kaolin?) orthoclase or untwinned albite feldspars; remainde, is quartz, chlorite, and sericitic muscovite.
Dominguez	8	Miocene	+		
Rosecrans	Odea	Miocene	+	0.29	Chiefly ca. equal amounts quarts and all types of fresh to highly altered feldspars yielding small crystals of indices both above and below balsam; identification indeterminate, may be montmorillonite, illite, sericite (fine-grained muscovite); ca. 5% biotite, and alterations tending to chlorite and iron oxides.
Rosecrans	Odea	Miocene	+	0.48	Similar to preceding.
N.E. Coalinga	Gatchell	Eocene	—	Nil	Ca. 60% quarts, 35% chiefly orthoclase and minor microcline and plagioclase feldspars; ca. 5% kaolinite or anauxite in aggregate grains of same dimensions as other clastic grains; traces chlorite, muscovite.
N.E. Coalinga	Gatchell	Eocene	—	Nil	Similar to preceding except that component believed to be kaolin is spread in patches of tiny micron-sized grains (pellets disaggregated in mounting?)

Table III — Preliminary Identification of Clays in Cores by X-ray Diffraction

Core		Size Fraction		
Field	Zone	40D2[c]	40D1[d]	E40D1[e]
Paloma	Stevens	"mont."[a,f] (ms)[g] quartz (s) feldspar (ms)	"mont." (s) quartz (m) feldspar (w)	"mont." (s) barite (ms)
Rosecrans	Oligo	"mont." (vf) kaolin (s) (oriented)	"mont." (w) kaolin (ms) (oriented)	"mont." (m) kaolin (m) (oriented)
Dominguez	Third	"mont." (m) kaolin (w) quartz (f)	"mont." (w)	"mont." (m)
N.E. Coalinga	Gatchell	kaolin[h] (vvs)	kaolin (s) (oriented) "mont." (vvf)	b

[a] The quotation marks indicate merely that the observed lines are associated with the montmorillonite group of clay minerals and that identification of the particular member or members is uncertain.
[b] Insufficient sample for analysis.
[c, d, e] See corresponding footnotes to Table IV.
[f] Relative Order of "Montmorillonite" Content
40D2: Paloma > Dominguez > Rosecrans > N.E. Coalinga
40D1: Paloma > Dominguez = Rosecrans > N.E. Coalinga
E40D1: Paloma > Rosecrans > Dominguez.
[g] Visual comparison of the patterns for this core and kaolinite shows that they are exactly alike. Comparison with the anauxite pattern shows that some of the relative intensities of the lines differ but essentially the patterns are identical. It appears unlikely that, with our present technique, distinction between kaolinite and anauxite can be made with any degree of certainty.
[h] s = strong, m = medium, w = weak, f = faint, v = very.

In the interest of brevity only portions of the data obtained in the different examinations of the several cores are presented and discussed, since the primary purpose at this time is to indicate the efficacy of the combined usage of these methods. Toward this end, therefore, the main emphasis will be placed on the degree of correlation observed in the cases of the very differently water sensitive Paloma and Northeast Coalinga cores.[25]

A composite of the X-ray results in the preliminary identification of the clay minerals present in the colloid fractions of cores from each of the four fields studied is given in Table III. Table IV presents the cation exchange capacities of the sand, silt, and clay fractions for all of the cores. In the case of the Paloma and Northeast Coalinga cores direct comparisons of the X-ray diffraction patterns, electron micrographs, and infrared absorption spectra are given in Figs. 2, 3, and 4, respectively. The correlations of the fine fractions identifications for these cores obtained by the six different methods of analysis are given in Table V.

Examination of these data indicate the following:

1. The cation exchange capacities are generally proportional to the particle size. The exceptions may be caused by incomplete fractionation, error in the exchange capacity determination, or they may be real. The recent work of Johnson[26] which demonstrates that the lateral surface and exchange capacities for both montmorillonite and kaolin are inversely related makes the latter not likely. This conclusion is supported by the results of Grim and Bray[27] in their study of the base exchange capacity as a function of particle size for a wide range of clays. A plausible source of relatively high exchange capacity in the largest fractions may lie in the inability to separate from the unaltered feldspar component the diagenetically developed clay particles in which resides the exchange capacity. Further petrographic and supplementary work is necessary to clear up this point.

2. The exchange capacity data are inconclusive as regards correlation with susceptibility to fresh water damage. Thus, the Dominguez cores of both relatively high and low water sensitivity all have relatively higher exchange capacity clays than the more sensitive Paloma cores. This inconclusiveness, to some extent, may stem from the fact that the samples are not clays exclusively but contain minerals of low or zero base exchange capacity, as indicated by the X-ray results of Table III.

3. The X-ray data of Table III, with the possible exception of the Rosecrans core, indicate a possible connection between the amount of bentonitic clay present and water sensitivity. Perhaps a more important factor than the amount of potentially swellable clay present is the manner in which such a clay component is interlaminated with the non-swelling minerals in the reservoir matrix.[11]

4. The degree of certainty with which the clay minerals fractions of the Paloma and Northeast Coalinga cores can be identified (Table V) appears to be dependent on the extent of correlation among the different tests employed. Thus, for the Stevens Zone fractions the X-ray patterns show the presence of montmorillonite group mineral, the electron micrographs are also vague as to the precise nature of the "montmorillonite" mineral(s), the petrographic description of the unfractionated core appears to gain in diagnostic significance in connection with the next three methods.

The chemical analysis of nearly four per cent K_2O is consistent with the presence of either illite and a lesser amount of potash feldspar or montmorillonite and a larger amount of the feldspar component in admixture with quartz; similarly the presence of montmorillonite, unaltered feldspar and quartz or a relatively large amount of illite with respect to quartz and/or feldspar can explain the 37.7 milliequivalents per 100 grams of cation exchange capacity resident in the coarse colloid and increasing toward the fine colloid fraction; finally, the infrared spectrum (Fig. 4) seems to be diagnostic for illite in giving a pattern very nearly the same as the pattern for the Grundy County, Illinois, illite of known structure and properties.

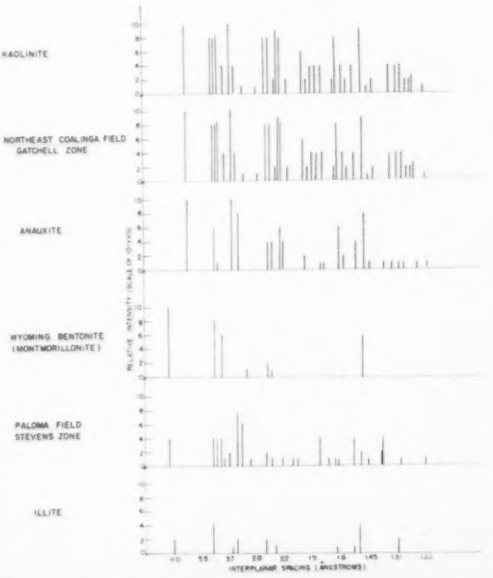

FIG. 2 — COMPARISON OF X-RAY DIFFRACTION PATTERNS OF CORE CLAYS AND CLAY MINERAL STANDARDS.

In the case of the Gatchell Sand the problem of identification is simpler beginning with any one of the six methods; the task in each case is to determine whether the kaolin is predominantly nearer in composition to kaolinite or anauxite (the other kaolin minerals dickite and nacrite have not yet been considered.) The X-ray patterns clearly identify the material as kaolin; the electron micrograph of the 9D3 silt fraction definitely indicates kaolinite but the micrograph of the 40D2 coarse colloid fraction is less diagnostic in that the very small particle size makes more difficult the differentiation between kaolinite and anauxite; chemical analysis based on the silica: alumina ratio of 2.7 indicates that the silt fraction in overall composition may approach anauxite with its theoretical silica: alumina mole ratio of 3; the cation exchange analysis correlates well with the known values for kaolin minerals and, finally, as in the case of the Stevens Zone fractions the infrared spectrum of the coarse colloid fraction indicates that the main component present, at least in this fraction, may be anauxite and not kaolinite (Fig. 4).

CONCLUSIONS

From the data and discussion, it is concluded that, for the particular cases of the Stevens Zone and Gatchell Sand cores, the clay minerals identifications are in harmony with the observed sensitivity of these strata to fresh water; *viz.*, the predominance of illite and/or "montmorillonite" in the Stevens Zone core is consistent with susceptibility to damage by fresh water; likewise, the predominance of kaolin as kaolinite, anauxite or both is in accord with the relative immunity of the Gatchell Sand to such damage.

ACKNOWLEDGMENT

The authors wish to thank the many members of the Research Department of the Union Oil Co. of California whose combined efforts aided in obtaining these results.

It is a pleasure, too, to record the contribution of Professor Ian Campbell of California Institute of Technology who performed the petrographic analyses and otherwise gave freely of his expert opinion. Finally, the authors wish to thank the Management of Union Oil Co. of California for permission to publish this paper.

Table IV — Cation Exchange Capacities[a] of Sand, Silt, and Clay Fractions of Selected California Cores

Core		Size Fraction					
Field	Zone	140–270 Mesh	<270 Mesh	Silt (9D3)[b]	Coarse Colloid (40D2)[c]	Fine Colloid (40D1)[d]	Superfine Colloid (E40D1)[e]
Dominguez	3	6.6	8.1	23.1	58.9	115	
Dominguez	3	6.8	10.0		53.5	106	
Paloma	Stevens	2.9	3.6	16.4	37.7	68.5	
Dominguez	Lower 7	3.7	6.7	26.6	95.0	53.9	43.0
Dominguez	Upper 8	9.1	17.2	24.2	65.3	102	
Dominguez[f]	8				97.1	50.9	
Dominguez[g]	8				73.5	105	103
Dominguez[h]	8	9.8	7.2	45.3	52.3	82.0	113
Rosecrans	Odea	9.4	8.0	21.2	56.7	96.5	
Rosecrans	Odea	9.9	15.3	29.5	40.2	(114)[i]	(65)[i]
N.E. Coalinga	Gatchell	5.1	3.4	2.4	16.6		38.5
N.E. Coalinga	Gatchell	3.0	5.0	2.2	12.1		

[a]The cation exchange capacity is expressed as milliequivalents per 100 grams.
[b]Fraction sedimented in bowl of 4.45 cm ID and 19.76 cm in length at 9,000 rpm using Drag No. 3 (flow rate of approximately 1,200 ml per minute).
[c]Same as [b], with Drag No. 2 but at 40,000 rpm and flow rate of 725 ml per minute.
[d]Same as [c], with Drag No. 1 but at flow rate of 138 ml per minute.
[e]Fraction recovered from effluent of 40D1.
[f]Core dispersed in distilled water without prior chemical treatment.
[g]Same core as [f] treated with 1N acetic acid and 1N ammonium acetate prior to dispersion in dilute aqueous ammonia.
[h]Same core as [f] dispersed in dilute aqueous ammonia without prior chemical treatment.
[i]Result is in doubt because sample could not be ground satisfactorily.

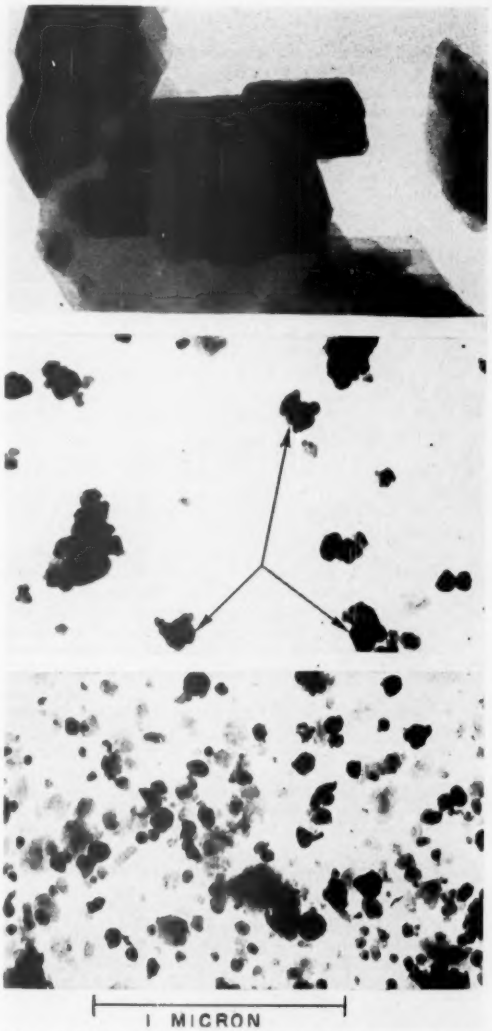

FIG. 3 — ELECTRON MICROGRAPHS OF CORE CLAYS. MAGNIFICATION X45,000. TOP — NORTHEAST COALINGA FIELD, GATCHELL ZONE, SILT FRACTION. CENTER — NORTHEAST COALINGA FIELD, GATCHELL ZONE, COARSE COLLOID FRACTION. BOTTOM — PALOMA FIELD, STEVENS ZONE, SUPERFINE COLLOID FRACTION.

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Table V—Correlation of Fine Fractions Identifications for Cores from Stevens Zone and Gatchell Sand

Method	Stevens Zone	Gatchell Sand
X-Ray Diffraction	40D2[a]: "montmorillonite" (ms)	40D2: kaolin (vvs)
	E40D1[a]: "montmorillonite" (s)	40D1: kaolin (s)
Electron Microscope	40D2: "montmorillonite" (illite?)	9D3[b]: kaolinite
	E40D1: "montmorillonite" (illite?)	40D2: kaolinite, anauxite
Petrographic	(on unfractionated core) mainly feldspars of sericitic alteration; to (illite?)	(on unfractionated core): kaolinite or anauxite
Chemical Analysis	40D2: 3.9% K_2O[a] (from illite and/or potash feldspar?)	9D3: SiO_2/Al_2O_3=2.7 (anauxite?)
Cation Exchange	40D2: 37.7 m.e./100 gm.	9D3: 2.4 m.e./100 gm. (kaolin)
	40D1: 68.5 m.e./100 gm. Montmorillonite	40D2: 16.6 m.e./100 gm. (kaolin)
Infrared	40D2: mainly illite	40D2: mainly anauxite

[a] By emission spectrographic densitometric comparison with the North Carolina muscovite and the two illites from Goose Lake and Fithian, Ill., described in Table I.
[b], [c] See Corresponding footnotes to Table IV.

FIG. 4 — COMPARISON OF INFRARED SPECTRA OF CORE CLAYS AND CLAY MINERAL STANDARDS.

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DISCUSSION

By W. T. Cardwell, Jr., Member AIME, California Research Corp., La Habra, Calif.

Among papers pertaining to this subject, the present paper is outstanding for its large amount of firsthand experimental information and its small amount of unsupported speculation.

It is especially noticeable that the authors have refrained from statements regarding the mechanism of formation damage by fresh water. They are evidently dissatisfied with the mere recitation that clays swell up and block pores. They state that "perhaps a more important factor than the amount of potentially swellable clay present is the manner in which such a clay component is interlaminated with the non-swelling minerals in the reservoir matrix."

I believe that the authors would agree that none of the analytical methods they have used tells whether a clay is a highly swelling clay. The identification of a clay as a member of the montmorillonite group is necessary, but not sufficient, because there are poorly swelling montmorillonites.

I should like to ask if the authors considered the performance of swelling tests on the fine fractions from the Stevens and Gatchell zones.

AUTHORS' REPLY TO MR. CARDWELL

The authors did consider the importance of determining the swelling characteristics of the fine fractions and believe that such data, were it available, would aid in study of the mechanism of formation damage by fresh water. Admittedly this study of swelling is one of many possible directions in which to continue the program as outlined in our paper. ★ ★

The Drift of Things

. . . as followed by **EDWARD H. ROBIE**
Secretary AIME

Efforts made by the national engineering societies and other professional organizations to see that professional and technical skills are utilized by the nation to better advantage in the present emergency than they were in World War II seem to be bearing fruit. Engineers Joint Council, of which the AIME is one of the five constituent societies, has been working actively to this end through its Engineering Manpower Commission. A representative from each of the three Branches of the AIME is on the Commission. The Commission's efforts have been centered in two directions: (1) To utilize present professional skills to the best advantage of the country, and (2) To provide for a continuing adequate supply of graduate engineers.

On March 31, President Truman issued an Executive Order amending the former Selective Service regulations. Thereby, all registrants would be deferred from military service if they are (1) engaged in research, medical, scientific, or other endeavors necessary to the maintenance of the national health, safety, or interest; (2) if the registrant cannot be replaced because of a shortage of persons possessing his qualifications for such service; and (3) if removal of the registrant would cause a material loss in the effectiveness of the vital activity in which he is engaged. Presumably, draft boards will be given specific direction as to what endeavors are "necessary to the maintenance of the national health, safety, and interest."

All students above a certain level of standing in their classes or whose score is sufficiently high in aptitude tests would be deferred. These levels have not yet been determined, the idea being that they will be raised or lowered as the demand for students in training changes. A grade of 70, or C, in college has been mentioned. It is believed that substantially all freshmen accepted for college entrance this fall will be deferred; about half of next year's sophomore class; two thirds of the juniors; three quarters of the seniors; and all full-time graduate students. Thus would be deferred perhaps 800,000 male nonveteran students. Objection has been offered to this rather wholesale deferment by numerous newspaper editors. They argue, rather convincingly, that the standards demanded are too low, that many students are taking curricula of no practical value in the present emergency, that many of those deferred are anything but outstanding students and unlikely ever to be of any exceptional value to the country for special needed skills, and that many equally promising boys are not in college. Also, they argue, much less convincingly, that this deferment of college students is a departure from the idea of universal military service. So it is, but that is the idea that we are trying to get across: That people with exceptional brains are more valuable to the country if they utilize these brains in productive ways than if they use them in military combat, wherein many would be lost.

As to the aptitude tests, they will be conducted at some 1,000 centers on May 26, June 16, and June 30. The cost to the registrants will be nil, except for traveling expenses to the testing center. There will be no second chance if the testee fails. The tests will be conducted by the Educational Testing Service of Princeton, N. J. (no connection with Princeton University). This organization has had wide experience in this field and customarily makes over a million aptitude tests a year.

The Engineering Manpower Commission should have available by May a bulletin giving in detail exactly what should be done by an employer who wishes to retain the services of a young man subject to the draft. In general, nothing should be done until the employee receives notice of forthcoming induction.

Technical Men in the Army

A few months ago an AIME member told us that a young man, upon induction into the Army, could request transfer to the Technical Services Command, and would then be sent to Fort Belvoir, Va., where he would be trained along the lines of his former schooling and experience. We followed this up, and received the following letter from Major General Edward F. Witsell, of the Adjutant General's office, Washington:

"There is no Technical Services Command. It is believed that your inquiry is in connection with technical services which are the Corps of Engineers, Signal Corps, Quartermaster Corps, Ordnance Corps, Chemical Corps, Transportation Corps, and Army Medical Service.

"The Department of the Army is making every effort to assign personnel where the fullest use may be made of their training and experience. All individuals upon induction are required to complete the course in basic training at one of the training centers and are not assigned to a post or unit until this course has been completed. This ensures that each enlisted man is properly trained in the event of combat and also enables the Army to determine how and where his abilities may be utilized to the fullest extent in meeting the needs of the services."

From an Englishman

Honorary Members of the AIME, whose number is limited to 20 living individuals, are always invited to sit at the head table at the Annual Banquet of the Institute. A few are able to come, and the invitation usually produces appreciative letters from some of those who can't. From C. McDermid, long a secretary of both the Institution of Mining Engineers, which is devoted to coal, and the Institution of Mining and Metallurgy, in London, came this message in January: "The invitation inspires afresh the great pride I have always felt for the honour conferred upon me by the Institute so many years ago; and brings comfort to me, in these truly horrible and anxious times, by reminding me that in my old age I still have a material, as well as a spiritual connection with your great country. Without its unswerving will and all-powerful support all that we and the rest of the free peoples hold sacred would be doomed to destruction, and the world to domination by the Devil for perhaps centuries to come!"

Sign of Senility

A verse that we were handed the other day reads as follows:

You're not getting old
When your hair gets gray;
You're not getting old
When your teeth decay.
But, boy, you're headed
For the last long sleep
When your mind makes plans
Your body can't keep.

Well, we think it would be even more serious if the last two lines read as follows:

When your body is willing
But your mind is weak.

Maybe not as good rhyming though. ★

Book Reviews

Liquid Extraction

By Robert E. Treybal, McGraw-Hill Book Co., New York, Toronto, London, 1951. 442 pp., illus., tables, 9¼ x 6¼ in., cloth, $7.50.

This book gives a review and organization of the subject matter of the unit operation of liquid-liquid extraction. Covered are the physical chemistry of liquid-liquid equilibria, prediction of equilibria, thermodynamics of nonideal solutions, choice of solvent, diffusion in liquids, theoretical discussion of mass transfer, design of extraction systems (flowsheets and equipment), description of equipment and operating characteristics, and a brief review of important modern chemical processes using liquid extractions.

Many diagrammatic illustrations are used and detailed tables of notation and literature references are given for each chapter. The author is professor of chemical engineering at New York University. The book is one of 31 in the McGraw-Hill Chemical Engineering Series.

Distillation Equilibrium Data

By Ju Chin Chu, Reinhold Publishing Corp., New York, 1950, 304 pp., tables, 9¼ x 6¼ in., cloth, $6.00.

This book offers vapor-liquid equilibrium data and makes available a reference to information concerning the design, performance prediction, and operating characteristics of distillation equipment in the petroleum and chemical industries.

It is divided into three parts: binary, ternary and multi-component systems, totaling 176. The tabulation includes all pertinent experimental results of workers in all parts of the world working with various types of equipment. At the end of the book is given a complete formula index to facilitate location of the various systems. Original references for all data are given.

Guide to Geologic Literature

By Richard M. Pearl, McGraw-Hill Book Co., New York, Toronto, London, 1951. 239 pp., 9¼ x 6¼ in., cloth, $3.75.

A basic reference work, this book presents a guide to the extensive world literature of geology, its subdivisions, and related fields. References to lists, indexes and bibliographies give a key to locating published literature on geology from the earliest dates to the present. Details on availability are given in many instances. The book covers abstracts, periodicals, index guides, public documents, newspaper articles, theses, books, organization bulletins and maps. A discussion of library facilities, catalogues, microfilms, and services is also included.

Petroleum Production Engineering: Petroleum Production Economics

By Lester Charles Uren, McGraw-Hill Book Co., New York, Toronto, London, 1950. 639 pp., diagrs., charts, maps, tables, 9¼ x 6¼ in., cloth, $7.50.

The third volume of the author's trilogy on petroleum production engineering, this book emphasizes the economic aspects of the industry, equally as important to the professional engineer as the technological aspects. The author interprets the basic principles of economics and business administration as they apply to the petroleum and natural gas industry. Among topics presented are the economic geography of petroleum, oil and gas land acquisition and control, labor management, oil industry taxation, cost accounting, conservation, and appraisal of oil and gas producing properties. Professor of petroleum engineering at the University of California, the author has taught a lecture course on oil economics over a period of 10 years. ★ ★ ★

Oregon Section Backs Hoover Foundation

The Herbert Hoover Foundation has recently been organized to own, operate, and control Hoover's boyhood home in Newberg, Ore., to restore it to its original condition, and to furnish it as nearly as possible as it was when he lived there as a boy.

Bert Brown Barker, president of the foundation, requests that interested AIME members send contributions to this project. Contributions will be allowable income tax deductions for federal purposes and in Oregon and California. All communications should be addressed to James F. Bell, Secretary, Oregon Section AIME, c/o Portland Gas and Coke Co., Public Service Building, Portland 4, Ore. The Oregon Section of the AIME has resolved to sponsor the collection of contributions, gifts, and Hoover mementos from Hoover's many friends and fellow members in the AIME who would like to see this old home preserved and made a national historic site. The project is being undertaken by the Section as a tribute to one of the nation's great presidents and as an honor to one of the Institute's outstanding past presidents. ★ ★ ★

Spangler, Peterson Receive AAPG Awards

Walter B. Spangler and John J. Peterson, Esso Standard Oil Co. geologists currently assigned to the Creole Petroleum Corp., Caripito, Venezuela, have been named by C. L. Moody, president of the American Association of Petroleum Geologists, as joint winners of the A.A.P.G. President's Award for 1951. Including $100 in cash, this award is made annually to the author, or authors, under 35 years of age, of the "most significant original contribution to petroleum geology" published in the monthly Bulletin of the Association during the previous year. The winning paper, selected by a national medal award committee headed by J. V. Howell, Tulsa, Okla., is entitled "Geology of Atlantic Coastal Plain in New Jersey, Delaware, Maryland, and Virginia." It was published in the January, 1950, issue of the A.A.P.G. Bulletin. ★ ★ ★

Meetings of Interest

Student chapter of AIME at the University of Southern California will hold its Second Annual Technical Session on May 25. Joint sponsors with the chapter are Pi Epsilon Tau, honorary petroleum engineering society, and AIME local section. The program will include presentation of technical papers by university students, papers and discussions by prominent men in the industry, and a banquet.

Meetings of Interest

The Second Annual Conference on Industrial Research will be held June 11-15 at Columbia University in New York City, under the sponsorship of the Department of Industrial Engineering. The program will emphasize personnel and communications in industrial research, and will include clinic sessions as well as lectures. Attendance will be limited to 60, and applications will be accepted in the order of their receipt.

This aerial photo shows (by means of the dotted line) the move of the Petroleum Branch headquarters in Dallas. At the right terminal of the dotted line is the Continental Bldg., home of the branch from 1946 to 1951. At the left terminal of the line is the Trinity Universal Bldg., located at the corner of Harwood St. and Ross Ave.

Dallas Chamber of Commerce Photo

Petroleum Branch Effects Headquarters Move

ON APRIL 28, members of the staff of the Petroleum Branch office in Dallas rounded up all their paraphernalia and moved their base of operations ten blocks away. Reason for the move was a need for more space. The relocation proved to be a good business move. Statisticswise, the Branch gained 29 per cent more office space for only 5 per cent more annual rental. And for the first time in a year and a half, it had a little elbow room.

It was in April, 1946, that the Petroleum Branch first established its headquarters in Dallas in order to be centrally located in the industry's most productive domestic areas. At that time there were two persons on the staff occupying one room at the old address (601 Continental Bldg.). In January, 1949, publishing headquarters for the JOURNAL OF PETROLEUM TECHNOLOGY was moved from New York to Dallas, expanding the staff to four persons. At this time, two more rooms were added to the office space. The Branch headquarters was then occupying 823 sq ft.

In January, 1950, another staff member was added to compose data for the *Oil and Gas Development and Production* volumes. Space was adequate, though cramped, for the five staff members during the normal functioning months of the year. However, during the months of June through September, it becomes necessary to employ three part-time persons to help prepare preprints for the fall meetings. The existing space then became wholly inadequate.

An extensive search was made for more space with the thought that it would be undesirable to increase rental costs at this time. This latter factor precluded any idea of renting additional space during the "preprinting season." No other space was available in the Continental Bldg. It was found that by moving a few blocks in the downtown area, highly suitable space could be had for $3.25 per sq ft. A committee of AIME members (made up of R. E. Heithecker, D. V. Carter and H. B. Renfro) studied and approved this plan.

The best space was found to exist at 408 Trinity Universal Bldg. which now houses Branch headquarters. A one-year lease (with option to renew) was signed for 1,065 sq ft at an annual cost of .75 cents less per ft than was previously being expended.

OFFICE INTERIOR — Outer office of new Branch headquarters is pictured here. Door to left leads to Branch Secretary's office, one to right leads to editorial office. To the right, out of picture, is storeroom.

BUILDING EXTERIOR — New location of Branch headquarters is the Trinity Universal Bldg., ten blocks from heart of Dallas.

Personals

PAUL D. FOOTE, vice-president of Gulf Oil Corp. in charge of research and development, was presented with the Outstanding Achievement Medal Award of the University of Minnesota at Minneapolis on April 19. The honor is reserved for former students who have attained high eminence and distinction. It was conferred as part of the University's centennial observances during the dedication of new social science and liberal arts buildings. Foote, who received his Ph.D. in physics from the University in 1917, has played a leading role in developing the Gulf laboratories at Harmarville, Pa., into one of the nation's major industrial research centers.

+

CHARLES J. PENN is now editor of *Petroleum Register*. His address is International Petroleum Register, Los Angeles.

+

JOE A. PERRY, formerly with Barnsdall Oil Co., Victoria, Tex., is now with the Sunray Oil Corp., Alice, Tex.

+

DOUGLAS M. POGUE, Tulsa, has joined the Magnolia Petroleum Co., Morgan City, La.

+

AUGUSTIN PYRE is now with the Danish American Prospecting Co., Copenhagen, Denmark.

+

LESLIE B. RIGGINS, JR., is now located in Talara, Peru, with the International Petroleum Co., Ltd.

+

EDWARD E. ROTHROCK, formerly located at Mt. Carmel, Pa., is now at Midland, Tex.

+

DEWEY J. SABIN, previously with Standard Oil Co., has accepted a position with the Sohio Petroleum Co., Oklahoma City.

+

JAMES A. SMITH has joined Sun Oil Co. production laboratory, Beaumont, Tex.

F. M. COLE, petroleum engineer, was elected a vice-president of the Honolulu Oil Corp. at the April 17 meeting of the board of directors. Cole has been with the organization since 1937, and has been assistant to the executive vice-president since 1947.

+

H. ROSS BOLTON is now chief engineer for the Deep Rock Oil Corp., Tulsa. He had been division petroleum engineer for the Ohio Oil Co., Terre Haute, Ind.

+

A. H. CHAPMAN, Arabian American Oil Co., is now located at Washington, D. C. He had previously been in the New York office of the same firm.

+

PHILLIP G. COOK has joined the Union Oil Co., Whittier, Calif.

+

JOHN R. EVANS has become associated with the Seaboard Oil Co., Midland, Tex.

+

ARTHUR ALDEN GENTRY, Pan American Production Co., Houston, has been transferred to the Lyford, Tex., office.

+

JOSEPH C. GORDON, JR., is now working as a roughneck on the engineering training program for Magnolia Petroleum Co., Beaumont, Tex.

+

AUSTIN GROENEMAN has accepted a position with the Magnolia Petroleum Co. at the Hickok gasoline plant near Ulysses, Kans.

+

MIHRAN KHAYAN is now with the Mene Grande Oil Co. C. A., Barcelona, Anzoategui, Venezuela.

+

DENNIS L. KREHBIEL has joined with Sinclair Oil and Gas Co., Thrall, Kans.

+

ARCHIBALD MC. LAURIE has accepted a position with the Kern Trinidad Oilfields, Ltd., San Fernando, Trinidad, B. W. I.

+

GEORGE W. LEVANGIE, formerly located in Doylestown, Pa., is now with the Cia de Petroleo Genso Azul, Lima, Peru.

+

WILLIAM J. MANNAS, Pure Oil Co., Chicago, has been transferred to the Fort Worth office of the same company.

MARK OLSON is now general manager of operations for C. J. Brown, independent oil operator at Houston, Tex. Starting as a roughneck in the oil fields, Olson graduated as a petroleum engineer from the New Mexico School of Mines in 1942. Subsequently he worked with Stanolind Oil and Gas Co. in West Texas as engineer, Lubri-Gel Products Co. as chief drilling engineer, and Continental Oil Co. as district engineer in Southwest Texas. Since April, 1950, he has been international editor of World Oil magazine.

+

TODD C. STORER, field engineer, is now located at Corpus Christi, Tex.

+

BILLIE W. WALDEN is now production engineer, Cities Service Oil Co., Oil Hill, Kans.

+

THEODORE G. WARD, JR. has accepted a position with the Reno Oil Co., Wichita Falls, Tex.

+

JAMES E. WERNER is now employed by the Alcoa Mining Co., Houston, as a petroleum geologist.

+

CONNIE L. WILSON, formerly with Cities Service Oil Co., has joined the Sinclair Oil and Gas Co., Fort Worth, Tex.

+

W. E. WINN is now agent for the Ashland Oil and Refining Co., Dallas.

+

LEROY C. WITT, JR., has joined the Continental Oil Co., Los Angeles.

+

ROGER D. STANWOOD, formerly with Tide Water Associated Oil Co. for more than 11 years and recently Assistant Superintendent of its Gas Utilization Department, has accepted the position of assistant to the vice-president of gas supply of Transcontinental Gas Pipe Line Corp. A native of Boston, Mass., Stanwood is a graduate of Dartmouth College in 1939. He assumed his new duties on March 16 in Houston.

Gas Technology Course Sponsored by Texas A&I

The Texas College of Arts and Industries at Kingsville, Tex., will be the site of the Sixth Annual Short Course in Gas Technology to be held May 30 through June 1. Sponsored by the Southern Gas Association, the course is styled so that once a year technical developments within the industry are presented through classroom lectures and discussion to those who have an interest in the problems of production, transmission or industrial utilization of natural gas.

The three-day program will be divided into two sections; one on the latest methods for solving important problems of production and transmission of gas, and the other on improved techniques in the utilization of natural gas. Chairman for the former section will be Carl E. Cloud of the Oklahoma Natural Gas Co., Tulsa; and chairman for the latter section will be C. L. Brockschmidt of the Texas Eastern Transmission Corp., Shreveport, La.

Some 20 papers will be presented during the Short Course. Enrollment will be limited to 150 persons, the enrollment fee being $30, which amount includes dormitory facilities and meals at the college. Applications for enrollment should be made directly to Short Course in Gas Technology, Texas College of Arts and Industries, Kingsville, Tex. ★ ★ ★

AIME Members Appointed To World Congress Posts

Four AIME members have been appointed to responsible positions in connection with the Third World Petroleum Congress, to be held at The Hague, Netherlands, May 28 to June 6, 1951.

W. Alton Jones, president of Cities Service Co. and chairman of the board of API, was appointed to the Committee of Honour by the organizing committee of the Congress, and will represent the American Petroleum industry. W. E. Wrather, director of the U. S. Geological Survey, will represent the United States government on the Committee of Honour. He was selected by the Department of State.

E. V. Murphree, president of Standard Oil Development Co., is serving as chairman of the National Committee for the United States. Paul D. Foote, director of research for the Gulf Research and Development Co., is a vice-chairman of the committee. ★ ★ ★

East Texas Section Co-Sponsors Oil Library

The Ark-La-Tex Geophysical Society, the Shreveport Geological Society, and the East Texas Chapter of AIME have completed preliminary plans for a Petroleum Exploration Library to be housed in the Shreve Memorial Library, Shreveport, La.

Books and publications pertaining to the oil and gas industry are needed. The Library Committee has requested all persons to check through their personal collections for any material that they might be willing to contribute. Contributions should be delivered to Harry Buckner at the Carter Oil Co. If personal delivery is impossible, arrangements can be made to have them picked up by calling R. T. Wade, phone 3-3105; George Jenkins, phone 5-1521; or Harry Buckner, phone 2-8721. Contributors are requested not to deliver books or publications to the Shreve Memorial Library. ★ ★ ★

There Aren't Many Left!

We're talking about accommodations for the Petroleum Branch Fall Meeting in Oklahoma City.

IF YOU PLAN TO ATTEND — ACT NOW

Accommodations are no longer available at the Biltmore Hotel, headquarters for the meeting to be held Oct. 3-5. There are still rooms and suites set aside for AIME members at the Black, Huckins, Hudson, Kingkade, Skirvin and Wells Roberts hotels.

SEND YOUR RESERVATION IN NOW

Address it to the Biltmore Hotel. The manager there will arrange for your accommodations in one of the above-named hotels. Use the post card provided in your April issue of the JOURNAL OF PETROLEUM TECHNOLOGY. Do it now while you have time.

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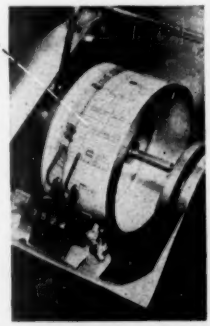

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Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 408 Trinity Universal Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded Y5261, Y5232, Y5204, Y5182 and Y5114 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

POSITIONS

♦ Engineer-designer with at least 10 years' experience in actual design work, including design of all types of petroleum refinery equipment, *i.e.*, vertical storage tanks, pressure vessels, high and low pressure piping, steel structures, etc. Will do designing for draftsmen, and assist draftsmen in laying out work and finishing the drawings. Will also check the draftsmen's drawings. Salary open. Location, Maryland. Y5261.

The Engineering Societies Personnel Service, Inc., has many outstanding engineering positions available throughout the United States and for foreign service.

Make your availability known to the office of the Engineering Societies Personnel Service, Inc., nearest to your home. Never before in the 30-year history of the Service have there been greater opportunities for members of the engineering profession in all branches, mechanical, electrical, civil, mining and metallurgical, chemical, naval architecture, etc.

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Chicago — 84 E. Randolph St.
San Francisco — 57 Post Street
Detroit — 100 Farnsworth Ave.

♦ Designing draftsman with five to six years' experience in layout of oil pipe lines. Salary, $5,500-$6,000 a year. Location, New York, N. Y. Y5232.

♦ Lubrication sales engineer, 32-40, with experience in sales of industrial and automotive lubricants, to sell lubricating oils and greases throughout Latin America. Considerable traveling. Must have knowledge of Spanish. Salary, $7,200 a year, plus expenses. Y5204.

♦ Geologists. Large corporation desires services on permanent basis of several senior geologists, having five to ten years' experience in mineral examination and exploration work. Salary open, commensurate with experience. Apply by letter. Location, domestic and foreign. Y5182.

♦ Geologists and petroleum engineers for staff positions covering administration of oil and gas production and conservation regulations. Location, western Canada. Y5114.

PERSONNEL

♦ Graduate petroleum engineer, 30, married, eight years' varied petroleum industry experience, desires responsible position as executive assistant or situation offering advancement commensurate with performance. Available on 30 days' notice in Chicago area. Will relocate. Code 146.

♦ Available to operator or small company superintendent. Graduate petroleum engineer with more than 20 years' experience in drilling and production. Code 147.

♦ Production engineer wishes to change employment. MS in petroleum engineering with three years' experience. Married, three children, 29 years old, veteran of the last war. Code 148.

♦ Petroleum engineer, 1947 graduate, wishes to change employment. Want active position pertaining to drilling, completion and production. Prefer to work for independent producer. All offers considered. Age 31, married. Code 149.

Proposed for Membership, Petroleum Branch

Total AIME membership on January 31, 1951, was 17,228; in addition, 4,613 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Thomas G. Moore, Chairman; Carroll A. Gorner, Vice-Chairman; George B. Carless, F. W. Hanson, Albert J. Phillips, Lloyd C. Gibson, R. D. Mallison, John T. Sherman. Alternates, A. C. Brinker, H. W. Hitzrot, Plato Malozemoff, Ivan Given, T. D. Jones, W. H. Farrand.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend privileges but does not desire to admit persons unless they are qualified. Objections on applications should be received on the 15th of the month following publication in PETROLEUM TECHNOLOGY.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

CALIFORNIA
Bell — Brazier, Richard M. (J).
Huntington — Godfrey, William K. (J).
Los Angeles — Pepperdine, George (J) (R, C/S-S-J).
San Diego — Scranton, James M. (J) (C/S-S-J).

KANSAS
Eureka — Lewis, Eugene F. (M) (C/S-J-M).
Wichita — Warren, Wyman M. (J) (C/S-S-J).

KENTUCKY
Pikeville — Finch, Byron M. (M).

LOUISIANA
Baton Rouge — Miller, Walter H., Jr. (J) (C/S-S-J).
Eunice — Slight, James W. (J).
Lafayette — Forney, Laurence B. (J) (R, C/S-S-J); Guidry, George E. (J).
New Iberia — Henderson, Joseph M. (M).
New Orleans — Kuhne, Edward B. (M) (C/S-A-M).

MINNESOTA
St. Louis Park — Johnson, James R. (J) (C/S-S-J).

MISSISSIPPI
Natchez — Lowrie, John D. (M) (C/S-A-M).

NEW YORK
New York — Clark, Ernest W. (M); Reynolds, Jordan K. (M).

OHIO
Cleveland — Wallace, Earl D. (M).

OKLAHOMA
Bartlesville — Morrow, Sam D., Jr. (J).
Norman — Genca, Melih I. (J) (C/S-S-J).
Ponca City — Greathouse, Walton D. (M).
Stilwell — Sanders, John L. (J) (C/S-S-J).
Tulsa — Haynes, George W. (M) (C/S-J-M); Ragan, Edgar D. (J); Stoner, Oscar E., Jr. (M); Woods, John W. (A).

PENNSYLVANIA
Bradford — Byrne, David T. (J) (R, C/S-S-J).
Duquesne — Linn, Earl H. (J).

TEXAS
Andrews — Rogers, Morgan G. (J).
Corpus Christi — Bielstein, Walter J. (M) (C/S-A-M); Williams, Davis C. (J).
Dallas — Sturdivant, Wilton C., Jr. (M).
Fort Worth — Nagle, Edgar T., Jr. (J); Raney, Donald R. (J).
Houston — Berry, Roy F., Jr. (M) (C/S-A-M); Carmargo, Orlando (J); Hood, James W. (M); Ruska, Walter E. A. (M).
La Feria — Dunlap, Bailey H., Jr. (J) (R, C/S-S-J).
Odessa — Martin, William H. (J); Simunick, Robert H. (J) (C/S-S-J); Williams, Jack C. (M).
Snyder — Eubank, Raymond H. (J) (C/S-S-J).
Tyler — Ervin, Percy S. (M).

UTAH
Salt Lake City — Harrah, Otto W. (A).

CANADA
Alberta — Gustafson, John D. (M).
Edmonton — Atkinson, Ralph F. (J) (R,C/S-S-J).

COLOMBIA
Bogota — Outmans, Harry L. J. C. D. (J).

MEXICO
Mexico — Skala, Hubert J. (M) (R, C/S-S-M).

★ ★ ★

Manpower

Continued from Page 20, Section 1

advisors to the Department of Labor (Executive Order 10161) for the petroleum industry.

3. When P.A.D. is organized, all requests for deferment of selectees should be cleared for justification through P.A.D.'s regional offices.

4. Affiliated reserve units — no deferments are to be requested.

5. In this period of partial mobilization the services cannot be expected to do a job of selectively calling up reserves if industry does not make the essential facts regarding the reservists available to them. It is the responsibility of the units (companies) of the petroleum industry to present these facts to the Defense Department.

6. It is being suggested to the Department of Defense and the P.A.D. that P.A.D.'s authority as manpower advisory claimant agency for the petroleum industry be expanded to include reserve personnel as well as inductees, so that an equitable division of essential personnel can be made.

FOREIGN OPERATIONS

Selectees

All U. S. citizens working outside the Continental limits of the United States who fall within the age brackets 18½-26 should have a letter from the draft boards responsible granting permission to reside outside the United States. It is understood that Selective Service is now arranging to have selectees residing abroad physically examined through our nearest Consul or Military Attache's office to save them the necessity of a trip back to the United States for this purpose.

Reservists

All reservists should file a letter with the appropriate headquarters of their service requesting permission to leave, or reside outside of, the Continental limits of the United States. ★ ★ ★

Cementing Practices

Continued from Page 21, Section 1

The large number of successful jobs over 500 ft from the shoe should be noted.

Under cementing data, slurry weight statistics show that the light weight slurries are more successful than those between 15 lb and 16 lb. Also, heavy slurries over 16 lb were successful. This may indicate the influence of slurry viscosity on mud displacement, since the light slurries with gel added and heavy slurries are both more viscous than the medium weight neat cement slurries.

The section on placement velocity gives results contrary to the general thought in the industry, in that the low velocities appear to give the best results. Only one bad cement job occurred in the Gulf Coast area, where the placement velocity was less than two ft per second. Additives seem to have little effect upon a cement job.

The majority of the wells classified as "other" were on the Gulf Coast, and 85 of the wells were given precautionary squeezes prior to completion. The statistics show that on 84 per cent of the Gulf Coast completions, precautionary squeezes were not used, and therefore that the majority of the industry is no longer using this method as a standard practice. The high percentage of success obtained without precautionary squeezes indicates that the practice is inadvisable except under extremely bad conditions.

During the last half of 1950 there were approximately 10,125 wells in which casing was run in the area under consideration and covered by the statistics. Therefore, the 1,176 that were analyzed represent 11.7 per cent of the total. From a statistical standpoint this sampling should give fairly dependable results, though by the laws of probability the samples should give a higher percentage of success than actually exists. It will be noted that in many places in the table the number of wells involved for particular sections are not great enough to present a picture that would be reliable.

It is believed that had the data been accumulated over a longer period of time and included a greater number of wells, it would have been found that bad cement jobs are obtained in almost all fields from time to time and that some particular fields are very bad offenders. ★ ★ ★

Oil Field Corrosion

Continued from Page 23, Section 1

metallurgical standpoint, involved the question that, if no corrosion inhibitors will retard pit formation on sucker rods, would it not be feasible to provide harder materials for rods and thus prevent corrosion fatigue. Brown suggested that by decreasing the corrosion, the fatigue strength of the rod is automatically increased, thus eliminating the necessity for a harder material.

Baker briefly discussed the use of cathodic protection in reducing corrosion due to current passage in casing. He pointed out that such was possible, but that, economically it was sometimes untenable because of the great amount of experimentation necessary to set up the right conditions and to determine exactly the points of entrance and egress of electric currents in oil well casings.

Warren pointed out that certain types of plastic coating have been successfully used on tubing in flowing or gas-lift wells in the Mid-Continent which produce large amounts of water along with the oil. He did, however, point out that temperature is a controlling factor in that excessive temperatures cause the plastic coating to be ineffective and also, that turbulence in too great amounts also causes abrasion and thus reduces the plastic effect. ★ ★ ★

Drilling Fluids

Continued from Page 26, Section 1

measured. Two cores were mudded off with the mud containing a commercial bridging agent, and two cores were mudded off with the mud containing no bridging agent. The return permeabilities were measured at several pressure drops with the oil permeability increasing with each increase in pressure drop. The use of a bridging agent gave a higher return permeability for both comparisons.

Wright concluded by stating that the application of the above tests was to evaluate completion fluids to indicate what kind of completion fluid should be used and to indicate what treatment may be necessary to improve the fluid.

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PETROLEUM BRANCH MEETING CALENDAR

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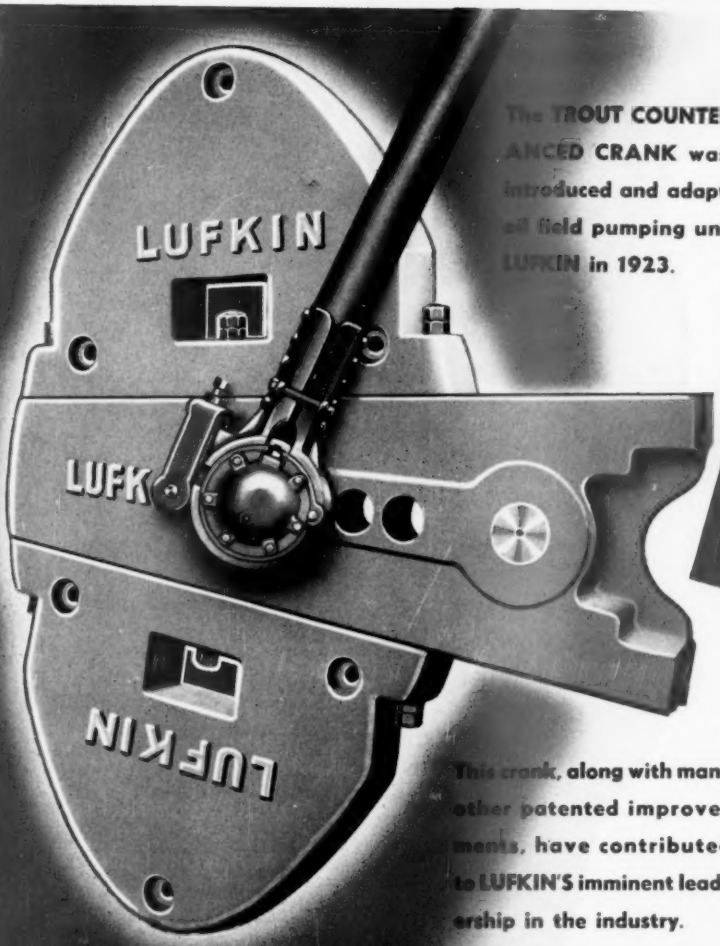
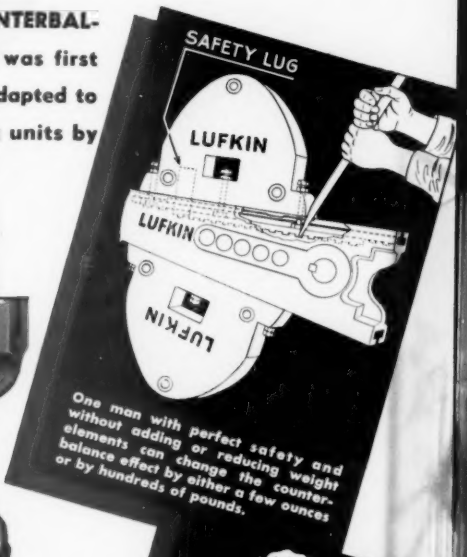
19	Southwest Texas Section
20	South Plains Sub-Section
20	Oklahoma City Section
24	Permian Basin Section
24	Pacific Petroleum Chapter

OCTOBER	
2	Delta Section
4	Illinois Basin Chapter
8	Mid-Continent Section
9	East Texas Section
16	Gulf Coast Section
17	Southwest Texas Section
18	South Plains Sub-Section
18	Oklahoma City Section
29	Permian Basin Section
29	Pacific Petroleum Chapter

LUFKIN LEADS!



The **TROUT COUNTERBALANCED CRANK** was first introduced and adapted to all field pumping units by **LUFKIN** in 1923.



One man with perfect safety and without adding or reducing weight elements can change the counterbalance effect by either a few ounces or by hundreds of pounds.

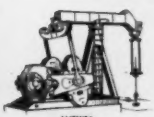
This crank, along with many other patented improvements, have contributed to **LUFKIN'S** imminent leadership in the industry.

On the smaller Lufkin Units, no tools, other than the wrench furnished with the unit, are necessary to enable one man to change counterbalance as desired.

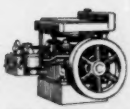
LUFKIN FOUNDRY & MACHINE COMPANY
LUFKIN, TEXAS

Branch sales and service Houston, Dallas, New York, Tulsa, Los Angeles, Seminole, Oklahoma City, Corpus Christi, Odessa, Kilgore, Wichita Falls, Casper, Wyoming, Great Bend, Kansas.

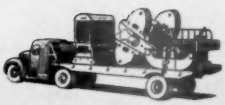
Lufkin Equipment in CANADA is handled by
THE LUFKIN MACHINE CO., LTD. 14221 108th Avenue, Edmonton, Alberta, Canada



LUFKIN PUMPING UNITS



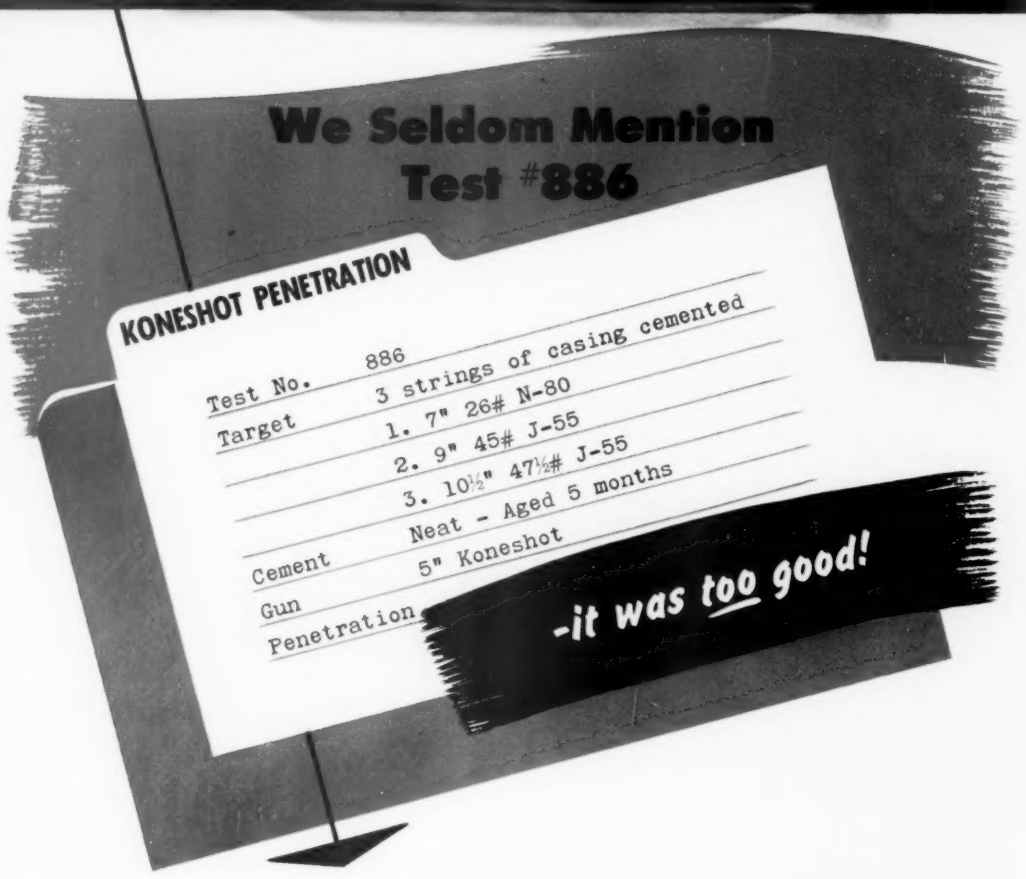
LUFKIN-COOPER-BESSEMER ENGINES



LUFKIN OIL FIELD AND INDUSTRIAL TRUCK TRAILERS

INDUSTRIAL SPEED REDUCERS AND INCREASERS

DIVISION LUFKIN FOUNDRY & MACHINE COMPANY
INDUSTRIAL, MILL AND AUTOMOTIVE SUPPLIES



It seems to us that it's better to tell you the *average* penetration . . . the results you can depend on . . . rather than quote the exception which, perhaps, you *might* get. That's why all the Lane-Wells tests on KONESHOT penetration were made under conditions which, as nearly as possible, duplicated actual operating conditions. And these are, briefly, the results:

AVERAGE PENETRATION			
	1 String	2 String	3 String
3⅛" gun	5¾"	5"	3½"
4" gun	7⅝"	7"	5"
5" gun	9"	7⅝"	7¼"

These are the figures that count—the actual penetration through casing and cement into the formation which you can depend on getting with KONESHOT, not once in a while, but *always!*

AK-401

ASK YOUR LANE-WELLS KONESHOT PERFORATING **LANE-WELLS MAN!**

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